Biomechanics and Medicine in Swimming XI

Per-Ludvik Kjendlie, Robert Keig Stallman, Jan Cabri (eds)
Biomechanics and Medicine in Swimming XI

Per-Ludvik Kjendlie, Robert Keig Stallman, Jan Cabri (eds)
Scientific Committee
Kjendlie, Per-Ludvik, NOR, (Chair)
Stallman, Robert, NOR, (Chair)
Cabri, Jan, NOR, (Chair)
Alves, Francisco (POR)
Arellano, Raul (ESP)
Aspenes, Stian (NOR)
Barbosa, Tiago (POR)
Castro, Flavio (BRA)
Chatard, Jean Claude (FRA)
Chollet, Didier (FRA)
Clarys, Jan Pieter (BEL)
Costill, David (USA)
da Silva, Antonio (POR)
Daly, Dan (BEL)
Dekerle, Jeanne (FRA)
Dopsaj, Milivoj (SRB)
Esser-Noethlics, Marc (NOR)
Fernandes, Ricardo (POR)
Hollander, Peter (HOL)
Issurin, Vladimir (ISR)
Jurimae, Toivo (EST)
Keskinen, Kari (FIN)
Langendorfer, Steven (USA)
Lemyre, Nicolas (NOR)
Mason, Bruce (AUS)
Millet, Gregoire (SUI)
Moran, Kevin (NZL)
Nomura, Teruo (JPN)
Ogita, Futoshi (JPN)
Onodera, Sho (JPN)
Payton, Carl (GBR)
Pendegast, David (USA)
Prins, Jan (USA)
Psychariakis, Stelios (GBR)
Pyne, David (AUS)
Rejman, Marek (POL)
Rodrigues, Ferran (ESP)
Sanders, Ross (GBR)
Seifert, Ludovic (FRA)
Stager, Joel (USA)
Swaine, Ian (GBR)
Toussaint, Huub (HOL)
Ungerechts, Bodo (GER)
Vikander, Nils (NOR)
Vilas-Boas, Joao Paulo (POR)
Wakayoshi, Kohji (JPN)
Zamparo, Paola (ITA)

BMS International Steering Group
Kari Keskinen, Finland (Chair)
Jan Pieter Clarys, Belgium
Bodo Ungerechts, Germany
Joao Paulo Vilas-Boas, Portugal

Local Organizing Committee
Robert Stallman (Chair)
Per-Ludvik Kjendlie (Chair)
Cabri, Jan (Chair)
Bakke, Tom Atle
Caspersen, Cecilie
Dahl, Dagmar
Keskinen, Kari (intn. advisor)
Midtun, Ingvild Riise
Olstad, Bjorn Harald
Steinbekken, Karoline
Vilas-Boas, Joao Paulo (intn. advisor)

Sponsors
The publishing of this book was supported by:
The Norwegian School of Sport Sciences
Department of Physical Performance
Norwegian Research Centre for Training and Performance
Norwegian Swimming Federation
Norwegian Life Saving Society
Norwegian Rheumatism Association
AP Lab
Coaches Infoservices
Cortex Biophysik GmbH
Hector Engineering Inc.
Ide AS
Klubben AS
Nespresso
Puhlen Norge
Sensorize Srl
Sport-Thieme GmbH
Tine AS
Vita
Voss Water
Preface

Biomechanics and Medicine in Swimming.
40 Years of Swimming Science.

The local organizing committee for BMS2010 is proud to welcome the delegates of the XI International Symposium for Biomechanics and Medicine in Swimming. It is an honor for us, for the Norwegian School of Sport Sciences, and for Norway, to host this unique conference and to present this Book of Proceedings. We feel that BMS XI is a reference work which covers the central advances in aquatic science since BMS 2006 in Porto and of which you will have considerable pleasure.

The International Symposium for Biomechanics and Medicine in Swimming remains the most prestigious of all aquatic oriented scientific congresses in the world. It has also retained its high ideal of the classic peer review process, so essential to scientific progress. Every submission has had the benefit of expert creative critique. Eleven times now, we have presented cutting edge research in a variety of aquatic activities and sports. Each time the challenge has been to present the best possible overview of the most important developments in the four year period since the previous BMS symposium.

The first symposium was held in Brussels in 1970 and it has now been held in ten different countries and on both sides of the Atlantic. Today, BMS has a unique place and a proud tradition. The series of eleven published BMS Proceedings has formed the backbone of literature in aquatic research for four decades. They are a collection of peer reviewed scientific papers commanding considerable respect and serving as a valuable resource for all who are interested in keeping up to date with aquatic research. Perhaps we should more properly be called a gathering of experts in aquatic human movement. Since the laws of nature are completely democratic, advances applied to one activity can also be applied to others. While the majority of papers lie within biomechanics, physiology and training, others are growing in popularity; sociology, education, psychology, anthropometry, epidemiology, drowning prevention, special needs swimming, learn to swim, life saving, etc. - all are represented.

It’s said that life begins at forty. We can thus expect the next forty years to be as brilliant as the last forty. The first edition of the proceedings (1971) gathered an intellectually rich mixture of the early pioneers, the established researchers and young, aspiring investigators. It read like the Who’s Who of aquatic research, including the pioneers T.K. Cureton Jr. who already in 1930 had published a biomechanical analysis of the crawl kick and Dr. Ernst Jokl. It also included established researchers of the day such as Dr. James “Doc” Counsilman who introduced us to Bernoulli’s principle as a possible explanation for propulsion in swimming and Dr. Per-Olof Astrand who introduced the first swimming mill or flume. Dr. Leon Lewillie and Dr. Barthels and Dr. Adrian introduced underwater electromyography. Dr. Mitsumasa Miyashita and Dr. Richard Nelson presented, at that time, sophisticated analyses of the crawl.

A systematic attempt to broaden the base of BMS characterized the Oslo meeting. Areas previously less well represented are present in larger numbers than ever before. This was extremely satisfying to us and we hope that the BMS family will continue this tradition. There are really three principles here which are important. Firstly, the quality of the research is what counts, not the activity to which it is applied. Secondly, by including more academic disciplines and aquatic activities, a far greater degree of cross-fertilization of ideas is possible. To give an obvious example, the biomechanical techniques applied to analyze competitive swimming can also be used to analyze recreational swimming, learn to swim, water polo and life saving. And thirdly, multi-disciplinary research will grow. We know that this is where reality is best mirrored.

The BMS Symposium 2010 includes 127 poster presentations, 125 oral presentations, three workshops and four poolside demonstrations. Also, nine keynote speakers presented outstanding lectures to the audience. The keynote speakers Dr. Stephen Langendorfer, Dr.
Nicolas Lemyre, Dr. Bruce Mason, Dr. Katszuo Matsuuchi, Dr. Jan Prins, Dr. Ferran Rodriguez, Dr. Annie Rouard, Dr. Ludovic Seifert and Dr. João Paulo Vilas-Boas are honored especially for their contribution. These contributions ensure that the essence of our conference series is passed on, and these backbone presentations present the current research in their respective fields. In honor of the BMS community's 40th anniversary, the first paper in this book is from the hand of Dr. Vilas-Boas and is entitled “Past, Present and Future of Swimming Science”.

The 147 papers in this book are organized into 6 different chapters, reflecting each paper's scientific discipline. We take also this opportunity to thank all of the authors who contributed to these papers. Their contribution often represents months of work, sometimes years. It builds on a lifetime of experience and collegial exchange of ideas, often these days, across international borders.

The BMS Symposium 2010 would not have been possible without our partners, exhibitors and sponsors. We thank The Norwegian School of Sport Sciences, The Norwegian Swimming Federation, The Norwegian Lifesaving Association and the Norwegian Rheumatism Association. This kind of contact between BMS and practitioners ensures that aquatic science adapts to, and studies real life, applied situations. We would also like to thank our sponsors and exhibitors for their contribution to making BMS 2010 happen;

All of the volunteers are thanked for making BMS a memorable conference. We hope you, in the midst of your hard work, gained valuable experience as well as enjoyable moments. The Scientific and Organizing committees provided laudable effort in preparing for this conference. We thank you deeply for your contribution. We thank also the International Steering Group of BMS for providing expert advice and for providing the continuity which has made 40 years of BMS possible. Finally we wish to honor The Norwegian School of Sport Science and its Rector, Prof. Sigmund Loland, for making BMS in Oslo possible. In difficult financial times all over the world, the support of The Norwegian School of Sport Sciences ensured the conference by providing the venue, pool, personnel and specifically sponsoring the banquet. Finally this book would not have been a reality without the editorial assistance of Bjørn Harald Olstad and Ingvild Riise Midtun.

We hope you will enjoy reading the contributions of this fine congress!

Per-Ludvik Kjendlie Robert Keig Stallman Jan Cabri

Oslo, June 16th 2010
Table of Contents

Preface 4
Biomechanics and Medicine in Swimming; 40 Years of Swimming Science. 4

Chapter 1. Invited Lectures 11
Applying a Developmental Perspective to Aquatics and Swimming – Langendorfer, S.J. 20
The Psycho-Physiology of Overtraining and Athlete Burnout in Swimming - Lemyre, P.-N. 22
Biomechanical Services and Research for Top Level Swimming: the Australian Institute of Sport Model - Mason, B.R. 25
Aquatic Training in Rehabilitation and Preventive Medicine – Prins, J. 28
Training at Real and Simulated Altitude in Swimming: Too High Expectations? - Rodriguez, P.A. 30
Muscle Fatigue in Swimming – Rouard, A.H. 33
Inter-Limb Coordination in Swimming – Seifert, L. 35

Chapter 2. Biomechanics 41
Effect of Stroke Drills on Intra-cycle Hip Velocity in Front Crawl – Arcellana R., Dominguez-Castelli R., Perez-Infantes E., Sánchez E. 45
The Usefulness of the Fully Tethered Swimming for 50-m Breaststroke Performance Prediction – Barbosa A.C. Milivcoj Dopsaj M.2, Okici T. Andrásio Júnior O. 47
Do Fastskin Swimsuits Influence Coordination in Front Crawl Swimming and Glide? - Chollet, D., Chevallard, E., Seifert, L., Lemaître, F. 55
The Effect of Wearing a Synthetic Rubber Suit on Hydrostatic Lift and Lung Volume - Cortez, M., Zamparo, P., Tam, E., Da Boit, M., Gatta, G. 57
The Development of a Component Based Approach for Swim Start Analysis – Cosson, J.M., Lawson, S.E.1, Justham, L.M., Conway, P.P., West, A.A. 59

Pulling Force Characteristics of 10 s Maximal Tethered Eggbeater Kick in Elite Water Polo Players: A Pilot Study - Dopsaj, M. 69
Motor Coordination During the Underwater Undulatory Swimming Phase of the Start for High Level Swimmers - Ellipot, M., 2, Houl, N. 2, Hellard, P. 2, Districh, G. 72
Measuring Active Drag within the Different Phases of Front Crawl Swimming – Formosa, D. P., Mason, B.R. & Burkhett, B. J. 82
The Mechanical Power Output in Water Polo Game: a Case Report – Gatta, G., Pantozzi, S., Cortesi, M., Patti, F., Bonfazi, M. 84
Comparison of Combinations of Vectors to define the Plane of the Hand in order to calculate the Attack Angle during the Sculling Motion – Gomes, L.E.1, Melo, M.O.1, La Torre, M. 1, Lou, J.F. 86
Relationship between Eggbeater Kick and Support Scull Skills, and Isokinetic Peak Torque - Hamma, M. 91
Comparison of Front Crawl Swimming Drag between Elite and Non-Elite Swimmers Using Pressure Measurement and Motion Analysis – Ichikawa, H., Miwa, T., Takeda, T., Takagi, H., Tsukakimoto, S. 100
Whole Body Observation and Visualized Motion Analysis of Swimming – Ito, S., Okuno, K. 102
A Full Body Computational Fluid Dynamic Analysis of the Freestyle Stroke of a Previous Sprint Freestyle World Record Holder – Key, M.F.1, Lytle, A.2, Blanksby, B.A.F & Cheng, L. 105
An Analysis of an Underwater Turn for Butterfly and Breaststroke – Kishimoto, T., Takeda, T., Sugimoto, S., Tsukakimoto, S.2 and Takagi, H. 108
Arm Coordination, Active Drag and Propelling Efficiency in Front Crawl – Seifert, L., Schnitzler, C., Alberty, M., Chollet, D., Toussaint, H.M. 115
Modelling Arm Coordination in Front Crawl – Seifert, L., Chollet, D. 117
A Method to Estimate Active Drag over a Range of Swimming Velocities which may be used to Evaluate the Stroke Mechanics of the Swimmer – Mason, B.R., Formosa, D.P., Toussaint, H.M. 124
50m Race Components Times Analysis Based on a Regression Analysis Model Applied to Age-Group Swimmers – Morales, E., Arellano, R., Femia, P., Mercado, J., Haland, R. 127
Regression Analysis Model Applied to Age-Group Swimmers: Study of Stroke Rate, Stroke Length and Stroke Index – Morales, E., Arellano, R., Femia, P., Mercado, J. 130
Influences of the Back Plate on Competitive Swimming Starting Motion in Particular Projection Skill; Kinematical Characterisation of a Basic Head-out Aquatic Exercise during an Incremental Protocol – Oliveira, C., Teixeira, G., Costa, M.J., Marinho, D.A., Silva, A.J., Barbosa, T.M. 137
Influence of Swimming Speed on the Affected- and Unaffected-Arm Stroke Phases of Competitive Unilateral Arm Amputee Front Crawl Swimmers – Osbrough, C.D., Payton, C.J., Daly, D.J. 140
Co-ordination Changes during a Maximal Effort 100 m Short Course Breaststroke Swim – Oxford, S., James, R., Price, M., Payton, C. 142
Preliminary Results of a “Multi-2D” Kinematic Analysis of “Straight- vs. Bent-arm” Freestyle Swimming, Using High-Speed Videography – Prins, J.H., Murata, N.M., & Allen, J. S. III. 154
Biomechanical Factors Influencing Tumble Turn Performance of Elite Female Swimmers – Pain, F., Martiller, J., Cid, M., Chollet, D., Hellard, P. 155
Identifying Determinant Movement Sequences in Monofin Swimming Technique – Rejman, M. & Starekiewicz, A. 160
Effects of a BlueseventyTM Bodysuit on Spatial-temporal and Coordinative Parameters During an All-out 50-m Front Crawl – Silveira, R.P., Kanojia, J.Y., More, F.C., Castro, F.A.S. 165
Fatigue Analysis of 100 Meters All-Out Front Crawl Using Surface EMG – Stiver, I., Jarm, T., Kapu, V., Strounik, V. 168
Comparison Among Three Types of Relay Starts in Competitive Swimming – Takada, T., Takagi, H., Tsukakimoto, S. 170
Aquatic Space Activities – Practice Needs Theory – Ungerechts, B., Klauck, J. 175
The Validity and Reliability of a Procedure for Competition Analysis in Swimming Based on Individual Distance Measurements – Vêga, S., Cala, A., González Frutos, P., Nacarros, E. 182
An Analysis of the Underwater Gliding Motion in Collegiate Competitive Swimmers – Wada, T., Sato, T., Ohishi, K., Tago, T., Isumi, T., Matsumoto, T., Yamamoto, N., Isaka, T., Shimoyama, Y. 185
Head Out Swimming in Water Polo: a Comparison with Front Crawl in Young Female Players – Zamparo, P., Falco, S. 187

Chapter 3. Physiology and Bioenergetics 191
Models of Vertical Swimming Abilities in Elite Female Senior Water Polo Players – Dopsaj, M. 192
Critical Velocity and the Velocity at Maximal Lactate Steady State in Swimming – Espada, M.A., Alves, E.B. 194
Modelling the VO₂ Slow Component in Elite Long Distance Swimmers at the Velocity Associated with Lactate Threshold – Hellard, P., Dohrle, J., Nesi, X., Toussaint, J.F., Houel, N., Hauswirth, C. 196
The Impact of Tension in Abdominal and Lumbar Musculature in Swimmers on Ventilatory and Cardiovascular Functions – Henrich, T.W., Pankey, R.B., Soskjaer, G.F. 199
Relationship between Propelling Efficiency and Swimming Performance in Elite Swimmers. – Huang, Z., Kurobe, K., Nishiwaki, M., Ozawa, G., Tanaka, T., Taguchi, N., Ogita, F. 201
Swimming and Respiratory Muscle Endurance Training: A Case Study – Lematre, F., Chevaillard, F., Chollet, D. 206
Heart Rate Responses During Gradually Increasing and Decreasing Exercise in Water - Nishimura, K., Noz, Y., Yoshioka, A., Kawano, H., Onohera, S., Takahato, N. 208

Effects of Recently Developed Swimsuit on Drag During Front Crawl Swimming - Ogita, F., Huang, Z., Kurobe, K., Ozawa, G., Taguchi, T., Tanaka, T. 211

Relationship between Heart Rate and Water Depth in the Standing Position - Onohera, S., Yoshioka, A., Matsumoto, N., Takahara, T., Nceu, Y. I., Hiromi, S., Seki, K., Nishimura, K., Bas, W., Hara, H., Murakawasa, T. 213


Hormonal, Immune, Autonomic and Mood State Variation in the Initial Preparation Phase of a Winter Season, in Portuguese Male Swimmers - Nama, L., Alves, F., Teixeira, A. 217

Oxygen Uptake Kinetics and Performance in Swimming - Reis, J.F., Alves, F.B. 220

Maximum Blood Lactate Concentration after Two Different Specific Tests in Freestyle Swimming - Rozi, G., Thanopoulos, V., Dospai, M. 222

Can Blood Glucose Threshold be Determined in Swimmers Early in the Swimming Season? - Sengoku, Y., Nakamura, K., Takeda, T., Nabekura, Y., Tsukimoto, S. 224

The Effects of Rubber Swimsuits on Swimmers Using a Lactic Acid Curve Test - Shira, T., Wakayoshi, K., Hata, H., Yamamoto, T., Tomikawa, M. 226

Some Factors Limiting Energy Supply in 200m Front Crawl Swimming - Szumbert, B., Usai, A., Kapus, J., Redmarik, J. 228

Lactate Comparison Between 100m Freestyle and Tethered Swimming of Equal Duration - Thanopoulos, V., Rozi, G., Platanou, T. 230

Blood Lactate Concentration and Clearance in Elite Swimmers During Competition - Vescovi, J.D., Falembuk, O., Weli G.D. 233

Determination and Validity of Critical Velocity in Front Crawl, Arm Stroke and Leg Kick as an Index of Endurance Performance in Competitive Swimmers - Wakayoshi, K., Shira, T., Ogita, F., Kita-jima, M. 236

Differences In Methods Determining The Anaerobic Threshold Of Triathletes In The Water - Zoretic, D., Werteimmer, V., Leks, G. 238

Chapter 4. Training and Performance 241

Physiological Responses and Characteristic Features of 200m Continuous Swimming and 4x50m “Broken Swimming” with Different Rest Intervals - Beidari, N., Botonis, P., and Platanou, T.242

General Indexes of Crawl Swimming Velocity of Junior Water Polo Players in a Match - Bratuta, F.Z., Persic, S.M., Dospai, J.M. 245

Bench Press and Leg Press Strength and its Relationship with In-Water Force and Swimming Performance when Measured in-season in Male and Female Age-group Swimmers - Carl, D.L., Leslie, N., Dickerson, T., Griffin, B., Marxsteiner, A. 247

Effect of Start Time Feedback on Swimming Start Performance - de la Fuente, B. and Arellano, R. 249

Predictors of Performance in Pre-Pubertal and Pubertal Male and Female Swimmers - Duoia, H.T., Touhkis, A.G., Georougi, Ch., Gourgeoulis, V. and Tokmakid, S.P. 252

Changes of Competitive Performance, Training Load and Tethered Force During Tapering in Young Swimmers - Drosin, E., Touhekis, A.G., Gourgeoulis, V., Thomaides, S., Duoia, H., Tokmakid, S.P. 254

Perceived Exertion at Different Percents of The Critical Velocity in Front Crawl - Franken, M., Diefenthauler, F., de Souza Castro, F.A. 257


Talent Progression in Young Swimmers - Hofmann, A.J., Steidel, I. 262

Determination of Lactate Threshold with Four Different Analysis Techniques for Pool Testing in Swimmers; Competitive Systematization in Age-group Swimming: An Evaluation of Performances, Maturational Considerations, and International Paradigms - Kojima, K. and Stager, J.M. 267

Effects of Reduced Knee-bend on 100 Butterfly Performance: A Case Study Using the Men’s Asian and Japanese Record Holder - Ide, T., Yoshihura, Y., Kassamot, K., Tatsie, S., Kawakami, T. 270


Effect of Subjective Effort on Stroke Timing in Breaststroke Swimming - Obba, M., Sato, S., Shimoyama, Y., Sato, D. 274


A Markov Chain Model of Elite Water Polo Competition - Pfiffer, M., Hofmann, A., Siegel, A., Bobeln, S. 278

Throwing Accuracy of Water Polo Players of Different Training Age and Fitness Levels in a Static Position and after Previous Swimming - Platanou, T. and Botonis, P. 281

The Effect of Cognition-Based Technique Training on Stroke Length in Age-Group Swimmers - Schmidt, A.C., Ungerechts, B.E., Bass, W.J., and Schack, T. 283

Assessing Mental Workload at Maximal Intensity in Swimming Using the NASA-TLX Questionnaire - Schnitzler, C., Seifert, L., Chollet, D. 286

Does the Y-Intercept of a Regression Line in the Critical Velocity Concept Represent the Index for Evaluating Anaerobic Capacity? - Shimoyama, Y., Okita, K., Baba, Y., Sato, D. 288


Identification of a Bias in the Natural Progression of Swim Performance - Stager, J.M., Brammer, C.L., Tanner, D.A. 294


Blood Lactate Responses During Interval Training Corresponding to Critical Velocity in Age-Group Female Swimmers - Tiali, G., Touhekis, A.G., Michailidou, D., Gourgeoulis, V., Douda, H., Tokmakid, S.P. 299
Monitoring Swim Training Based on Mean Intensity Strain and Individual Stress Reaction of an Elite Swimmer - Ungerechts, B.E., Steffen, R., and Vogel, K.  

302

Accelerometry as a Means of Quantifying Training Distance and Speed in Competitive Swimmers. - Wright, B.V., Hinman, M.G., Stager, J.M.  

305

Critical Swimming Speed Obtained by the 200-400 Meters Model in Young Swimmers - Zacca, R., Castro, F.A.S.  

307

Chapter 5. Education, Advice and Biofeedback 311


312

Quantitative Data Supplements Qualitative Evaluations of Butterfly Swimming - Becker, T.J., Havriluk, R.  

314

The Effect of Restricting the Visual Perceptual Task in the Temporal Organization of Crawl Swimming: Surface Characteristics - Brito, C.A.F., Belvis, W.C., Oliveira, M. 2  

317

Analyses of Instruction for Breath Control While Swimming the Breaststroke - Hashi, H., Yabuseda, A., Matsumoto, N., Nao, Y., Watanabe, R., Shibata, Y., Onodera, S.  

319

Performance Level Differences in Swimming: Relative Contributions of Strength and Technique - Havriluk, R.  

321

Evaluation of Kinaesthetic Differentiation Abilities in Male and Female Swimmers - Invernizzi, P.L., Longo, S., Scruati, R., Michielon, G.  

324

Swimming in Eyesight Deprivation: Relationships with Sensory-Perception, Coordination and laterality - Invernizzi, P.L., Longo, S., Tadini, F., Scruati, R.  

326

Progression in Teaching Beginning Swimming: Rank Order by Degree of Difficulty - Junge, M., Blixt, T., Stallman, R.K.,  

329

The Construct Validity of a Traditional 25m Test of Swimming Competence - Junge, M., Blixt, T., Stallman, R.K.,  

331

Using a Scalogram to Identify an Appropriate Instructional Order for Swimming Items - Langendorfer, S.J., Chaya, J.A.  

333


336

Shallow or Deep Water for Adjustment? A Study in Children Aged 3 to 6 Years - Scruati, R., Michielon, G., Longo, S., Invernizzi, P.L.  

339

The Effect of a Target Sound Made by a Model Swimmer’s Dolphin Kick Movement on Another Swimmer’s Dolphin Kick Performance - Shimojo, H., Ikibakasa, H., Tsukakimoto, S., Takagi, H.  

341

Tendencies in Natural Selection of High Level Young Swimmers - TimakovaT.S., Khlyuchenkova M.V.  

343

The Cognitive Interplay Between Sensory and Biomechanical Features While Executing Flip Turns Wearing Different Swim Suits - Vanluys, S., Ungerechts, B.E., Toussaint, H.M., lex, H. 1, Schack, T.  

346

The Role of Verbal Information about Sensory Experience from Movement Apparatus in the Process of Swimming Economization - Zaton, K.  

349

Chapter 6. Medicine and Water Safety 353

Crucial Findings from the 4W Model of Drowning for Practical and Teaching Applications - Avramidis, S., McKenna, J., Long, J., Butterfly, R., Llewellyn, J.D.  

354

Swimming, Cycling, Running and Cardiovascular Health - Bagheri, A.B., Mubebi, H.D., Avizi, M.H., Saiiari, A.R.  

357

Analysis of Aerobic/Aerobic Performance in Functionally Disabled Swimmers: Low Classes vs High Classes - De Aymerich, J., Benavent, J., Tella, V., Colado, J.C., Gonzalez, L.M., Garcia-Masó, X. 2, Madera, J.  

359

Athletic Rehabilitation of a Platform Diver for Return to Competition after a Shoulder Dislocation - Fujinawa, O., Kondo, Y., Tachikawa, K., Jigami, H., Hirose, K., Matsunaga, H.  

362

Comparisons of Water- and Land-based Physical Activity Interventions in Japanese Subjects with Metabolic Syndrome - Hanai, A. and Yamatsu, K.  

364


366

Real and Perceived Swimming Competency, Risk Estimation, and Preventing Drowning among New Zealand Youth - Morán, K.  

368

Keeping the Safety Messages Simple: The International Task Force on Open-Water Recreational Drowning Prevention - Quan, L., Bennett, E., Morán, K. (co-chairs)  

371

Immune Status Changes and URTI Incidence in the Initial 7 Weeks of a Winter Training Season in Portuguese Swimmers - Rama, L., Alves, F.B., Rosado, E., Azevedo, S., Matos, A., Henriquez, A., Pioza, A. 3, Teixeira, AM.  

374

Swimming Ability, Perceived Competence and Perceived Risk among Young Adults - Stallman, R.K., Dahl D.I, Morán, K., Kjendahl, P.L.,  

377

Movement Economy in Breaststroke Swimming: A Survival Perspective - Stallman R.K., Major J., Hamer S., Haavag G.  

379


381

A Conceptual Paper on the Benefits of a Non-Governmental Search and Rescue Organization - Wengelin, M., de Wet, T.  

384

Author Index 0
Chapter 1. Invited Lectures
The Leon Lewillie Memorial Lecture: Biomechanics and Medicine in Swimming, Past, Present and Future

Vilas-Boas, J.P.

University of Porto, Faculty of Sport, CIFI2D, Portugal

Biomechanics and Medicine in Swimming (BMS) is a series of international symposia organized every four years. The organizers are an International Steering Group, under the auspices of the World Commission of Science and Sport (WCSS), together with a competent Conference host. The WCSS is a working group under the umbrella of the International Council of Sports Science and Physical Education (ICSSPE), and its purpose is to promote the application of science to sport. The BMS series started in 1970, in Brussels, by the hands of Leon Lewillie and J.P. Clarys, with the first proceedings book published one year later. This paper aims to present an overview of, and synthesize the main axes of the contributions of the ten books published from 1971 to 2006, and to speculate about the future tendencies of the research and knowledge evolution in this specific domain.

Key words: biomechanics, medicine, swimming, research, review

INTRODUCTION

Biomechanics and Medicine in Swimming (BMS) is, in our days, a brand name that means "aquatic swimming science", despite that, in stricto sensu, it refers to two very specific fields of interest, practice, and research (Biomechanics and Medicine). The power and strength of the BMS brand name is mostly related to the popularity and scientific relevance of the "International Symposium of Biomechanics and Medicine in Swimming" series (firstly entitled "Biomechanics in Swimming"), whose 40th anniversary we celebrate in Oslo. Thanks to Leon Lewillie and J.P. Clarys, since 1970, and each four years, BMS is the meeting point of those that, worldwide, are struggling daily for the progress of knowledge in swimming science, and so progressively enlarging frontiers to new fields and topics. During this 40 year period, eleven scientific books related to swimming were published (the 11th being the present volume), all of them - and hopefully also this one - being determinant for the spreading and consolidation of swimming knowledge, and for the progress of aquatic swimming sports and activities. Despite this, it is not necessarily indexed scientific literature, though it is peer reviewed and globally the swimming science peer reviewed and indexed research activity that can more realistically express the importance of each topic. Thus, 159 entries were second or third entries of one paper, which means that 25.6% of the papers required second or third entries.

The analysis was performed considering the researcher's personal classification of each paper, considering, by order: (i) title; (ii) key-words; (iii) editorial classification, and (iv) content of the article. Some of the papers were the object of double or triple classification since they clearly affiliate to two or three categories. Consequently, the summation of the entries per category doesn't match with the total number of papers. The percentage analysis, however, was referred to the total number of papers analyzed (622), and not to the total number of entries (781), in order to more realistically express the importance of each topic. Thus, 159 entries were second or third entries of one paper, which means that 25.6% of the papers required second or third entries.

To allow further analysis of the findings, and trying to characterize more globally the swimming science peer reviewed and indexed research tendencies, a PubMed search was conducted on the 15th January 2010. The same percent distribution analysis and the same categories (with the exception of "Reviews") were considered for the search; dates were not restricted, and "Human" was imposed as a limit. "Miscellaneous" was assumed to be extractable from the subtraction of the sum of the output for the other selected categories to the total output of the search (9835 references).

RESULTS

The distribution of the 622 analyzed papers for the 10 books published between 1971 and 2006 is presented in Fig. 1.
A tendency can be perceived for a progressive increase in the number of papers published per book, particularly relevant in the last three editions, with a maximum value of 143 in 2006. Fig. 2 presents the number of different countries that contributed to the publication of each volume, considering only the affiliation of the first author. The covers of the different books allow the reader to keep in mind the variation rate of the number of published papers per volume. It can be observed that a greater number of countries contributed to the three last volumes, but this is in absolute values, not considering the increased number of papers. A relatively stabilised number of participating countries, at least in the three last events (about 20 to 25), can be perceived.

In Fig. 3, the number of papers published per country is presented. A total of 41 countries were considered (Curacao at the Netherlands Antilles, was considered a country). It is possible to verify that Japan, and the United States of America (USA), are the highest contributors to the total amount of published material. A second cluster seems to be composed of Belgium, France, and Germany, and a third one by Portugal, Spain, and the United Kingdom (UK). These eight countries (20% of the total 40 represented countries) are the greatest contributors, totaling 70% of the first author’s affiliation. The remaining 30% are spread among a total of 32 countries (80%).

In Figs. 4 and 5 a tendency can be observed in the following hierarchy of the research domains on the global BMS scene: (i) Biomechanics; (ii) Physiology; and (iii) Evaluation. It is also possible to perceive a tendency for the preservation of this hierarchy along the BMS series (book to book analysis). One of the noticeable exceptions is the reverse importance of Biomechanics and Physiology in BMS VI. A deeper analysis in this particular tendency shows a much stronger relevance of Biomechanics in BMS I to III, BMS IV is characterized by an increased importance of Physiology and Biophysics, which reaches a balanced status in BMS V, and overtakes Biomechanics in BMS VI. From BMS VII to X, Biomechanics regains the leadership to Physiology and Biophysics. Evaluation and Training seem to gain relevance only in the second part of the series.
perceived tendency for stabilization during the last three volumes. In the mean time, analysis may also reflect the attraction of the conference (program, host institution and geographical location), and not necessarity the distribution of swimming scientists over the planet. In this regard, a detailed analysis reveals also some interesting findings. For instance, despite Japan always being represented, its representation was elevated in BMS VIII and remains so until today. The participation of the USA can be analyzed in the opposite direction. American scientists assumed a serious predominance during BMS I to III, and VI and VII, but seem to retract afterwards. Another perceived effect, particularly in the last editions, was a “house effect”, meaning an increase of the participation of scientists from the organizing country, or from countries in the neighborhood. This was clearly perceptible in BMS I to V, VII, IX and X, and partially in BMS VIII, with an increased participation of Russian scientists. Finally, the affiliation analysis revealed that eight countries (20%), divided into three groups, are responsible for 70% of the published material, which evidences an excessive centralization that must be reduced in the future through international partnerships with less represented countries.

Analyzing the distribution of the published papers by the research domain categories selected for this study, a tendency can be found, as stated before, for a prevalence of Biomechanics over Physiology (including Biochemistry, Nutrition, and Thermoregulation) and the other domains. This is not in accordance with previous results reported by Clarys (1996, Foreword to BMS VII) about swimming research, nor with the results extracted now from PubMed (Figure 7).

It is perceivable from Fig. 7 that the BMS series seems to over represent the relative importance of Biomechanics in the scene of global swimming science production. The origin of the series (“Biomechanics in Swimming”) might be considered the first determinant factor of this situation, afterward preserved in time (with the exception of BMS VI), but other reasons should be examined, such as the relevance of swimming technique and biomechanics in the context of the determinant factors of swimming competitive performance. The nature and main focus of the data base searched might also have contributed to this perceived effect. In the case of the PubMed search, the predominant role of the medical areas might determine a higher presence of papers from the Physiology and Medicine domains. This hypothesis is consistent with the finding of an increased importance of these scientific fields (Physiology, Medicine, Biophysics) in the BMS IV, which includes the proceeding of both the 4th International Symposium of Biomechanics and Medicine in Swimming, and the 5th FINA International Congress.
on Swimming Medicine, and marked the first impulse for the increase of these areas in the BMS series. From the compared evidence, however, it should be supposed that the BMS series still supports the relevance of Biomechanics compared to other swimming science domains, an importance which, considering the global scientific scene, should be reinforced in the future.

A DEEPER ANALYSIS OF BMS SERIES CONTENTS

Despite previous data suggesting that the BMS series is not coping with the general progression of scientific research regarding the balance between different scientific domains, its deeper content analysis seems to clearly demonstrate that BMS books played, and continue to play, a decisive role in the promotion and spreading of swimming scientific knowledge, always keeping pace with peer reviewed indexed literature, but particularly assuming a very relevant catalytic role in encouraging future steps forward in the progress of swimming science. It is obvious that the BMS series does not contain all the relevant swimming research, not even in the biomechanics domain, but it can be hypothesized that the knowledge included satisfactorily covers all, or almost all, of the relevant progresses that swimming science has achieved over the years. We will now survey the ten BMS books (I to X, disregarding their original titles), highlighting those contributions that, in our view, strongly contributed to the above named effects. We will focus our attention mainly on both experimental and theoretical original contributions.

BMS I (1971)

In this volume, Counsilman introduced the revolutionary concept of quasi-static lift (L) theory on human swimming propulsion (P), and Kent and Atha analysed different transient body position effects on breaststroke drag (D) using passive drag towing methodology, but suggesting the need of future active drag (Da) assessments. P and D periodical changes during a swimming cycle are expected considering coordinative analysis (Nemessuri and Vaday; Vaday and Nemessuri), as well as, consequently, the existence of an acceleration profile, represented by intra-cycle velocity variations - IVV (Miyashita). The Astrand and Englesson “Aquatic Swim-mill” - the first swimming flume -, was probably the “must” in instrumentation progress presented in BMS I. The first results on VO\textsubscript{2} measurements at different velocities using this ergometer were produced by Holmér. Goldfuss and Nelson related swimming actions to the measured tethered force exerted by the swimmer, in what seem to be the first combination of both image and force data. Electromyography - EMG - (Barthels and Adrian) was also used as it was assumed to be the “unique” solution to monitor muscular activity during swimming despite serious normalization difficulties (Lewillie).

In parallel to the presented experimental approaches, Seireg and Bax presented the first complete mathematical analysis of the human biomechanics of swimming in the sagittal plane (x and y equations of linear motion and z joint torques).

BMS II (1975)

This volume fulfilled some of the higher expectations that emerged from the previous book. Serious improvements occur in the development of new instrumentation, namely for image acquisition, particularly to allow dual-media observation of the swimmer (under and overwater views) (McIntyre and Hay). Van Manen and Rijken resume the experiments conducted in The Netherlands Ship Model Basin, underlining the “towing carriage” that allowed new incursions in the measurement of P and D. In this regard, a very contemporary question was discussed in those days: the effect of swimsuits on D, showing that wearing a suit, combining load (positive and negative extra loads), the energy cost of swimming and efficiency (e), following one of the most well-known swimming biophysical relationships: VO\textsubscript{2}/d = Da/e, where VO\textsubscript{2} is the aerobic exercise Oxygen consumption subtracted of the basal VO\textsubscript{2} and d is swimming distance. The authors concluded that men have a higher Da and energy cost (VO\textsubscript{2}/d) than their female counterparts and a similar e, and that VO\textsubscript{2}/d rises with hydrostatic torque. Holmér used the same approach, and concluded that Da values are 1.5 to 2 times higher than passive D.

The importance of IVV analysis was once more stressed. Bober and Czabanski used the IVV combined with film images to investigate breaststroke coordination changes with mean velocity and Barthels and Adrian related hand kinematics with hip acceleration using film analysis. Sixteen millimeter film was also used, synchronized with EMG telemetric signals, to evaluate handicapped swimmers performing breaststroke, front crawl and backstroke (Maes et al.).

As in BMS I, also in BMS II some essays on mathematical modeling were published (Francis and Dean; Jensen and Blanksy).

BMS III (1979)

The third volume was biomechanically marked by two contributions extensively referred to in swimming literature, one related to D, and the other to P. Clarys extensively reviewed the state of the art in D hydrodynamics and its relationship to morphology, and used the already described “Towing Carriage” to assess Da. On the other hand, Schleihauf developed and experimentally supported the L and propulsive drag (Dp) theory of swimming propulsion. Once again the global dynamical effect of P and D changes during the stroke cycle motivated researchers to analyse IVV: Holmér used linear accelerometry and integration to assess swimming velocity, and Vervoort and Persyn analysed coordination of the breaststroke kick related to anthropometric, flexibility and force data. Piette and Clarys used an EMG telemetric system to compare competitive and non-competitive front crawl swimmers using different normalization procedures and Okamoto and Wolf reported, for the first time in the BMS series, the use of fine-wire electrodes in the aquatic environment.

In BMS III only one mathematical modeling approach to swimming biomechanics was included (Jensen and McIlwain), aiming to estimate segmental forces and joint torques in the dolphin kick. Swimming starts, however, were extensively studied (Disch et al.; Stevenson and Morehouse; Zatsiorsky et al.), and the first paper on swimming turns of the series appears (Nicol and Krüger), studying the forces exerted on the wall using force plates.

BMS III also included several relevant contributions on “Training Methods”, starting the tendency for a progressive enlargement of the interest domains of the series.

BMS IV (1983)

This volume was a combined proceedings book of the Biomechanics in Swimming and the FINA Swimming Medicine congresses, promoting an increase of the included scientific domains. P and D were, once more, central topics. Schleihauf et al. extended previous contributions to the study of the propulsive potential of the forearm and to arm joint torques. Still in the P domain, one of the first papers on the propulsive effect generated by undulatory swimming movements was included, comparing dolphins and butterflies (Ungerchets), underlining the importance of the quantification of the added mass effect to understand P and D. In another paper Ungerchets showed that the Re number does not represent satisfactorily the flow regimen around bodies that change form periodically, providing a historical contribution to the hydrodynamics of swimming. Da was once again revisited (Kemper et al.). It was shown that for much higher velocities (1.73 vs. 1.15 m/s), skilled swimmers are submitted to a much lower Da value (32.2 vs. 57.0 N), though passive drag values are similar at 0.75 m/s (22.5 vs. 21.2 N), relatively to their non-elite counterparts. Ohmichi et al. (1983) measured the waves caused by swimmers using a “Wave High Meter”, and comparing different velocities and strokes.

Nigg proposed a model to estimate the added work associated with IVV in swimming (3% extra work performed for velocity variations of
about 10%), underlining the importance of simultaneously considering both energy cost and its biomechanical determinant factors. Holmér elaborated on the swimming economy of the four competitive strokes, relating it to P, D, IVV and buoyancy.

Training contributions were scarce (Miyashita and Kanehisa), or partially hidden by their common physiological (Cazorda et al.; Nomura; Treffene), biomechanical (Schleihau) or EMG (Olbrecht and Clarys) content. However, physiology and thermoregulation presented relevant and innovative contributions (Chattard et al.; Craig; Nielsien; Nováč et al.; Zeman et al.). Decisive, also for its rarity as a longitudinal design, and for the preservation of the Swedish tradition in this regard, was the five year follow-up physiological study of Gullstrand and Holmér. Lavoie et al. presented the backward extrapolation method for the assessment of VO₂ in swimming reducing the mechanical constraints imposed by masks and tubes.

BMS V (1988)

One of the main topics was, once more, the P production mechanism. Although De Groot and Van Ingen Schenau theoretically demonstrate why L dominated propulsion is more efficient than Dp dominated P forces, Ungerechts showed that peak acceleration of the breaststroker during the kick happens near the turning phase of the feet, suggesting that a quasi-static approach to the hydrodynamics of P in swimming seems to be insufficient. In parallel, Shleihauf et al. went even deeper in the quasi-static propulsion theory, and provided evidence of four propulsive phases in backstroke arm action. Concerning D, the ‘MAD-System’ was referred to in the series for the first time. A very creative use of the device allowed Hollander et al. to show that the leg contribution to total power output in front crawl is only slightly higher than 10%. Toussaint et al. used the same system to show that propelling efficiency decreases with swimming v (r = -0.84) between 1.05 and 1.3 m/s. The EMG validations of the ‘MAD-System’ (Clarys et al.) and tethered swimming front crawl (Bollens et al.) were also provided. Consequently, the relationships between stroke frequency, tethered force and EMG, found by Cabri et al., gained increased relevance for front crawl performance analysis.

Using inverse dynamics from the IVV curve, Van Tilborgh et al. calculated the resultant impulses per phase of the breaststroke technique, emphasizing the importance of body undulation in this technique. This was one of the few studies of this volume centered on IVV assessment. However, this parameter was the basis of a historical paper on swimmer training and advice (Persyn et al.), integrated with force and performance analysis. The authors also found higher propulsive drag than lift components in each phase of the freestyle arm-stroke cycle, concluding that a quasi-static approach to the hydrodynamics of P in swimming seems to be insufficient. In parallel, Shleihauf et al. went even deeper in the quasi-static propulsion theory, and provided evidence of four propulsive phases in backstroke arm action. Concerning D, the ‘MAD-System’ was referred to in the series for the first time. A very creative use of the device allowed Hollander et al. to show that the leg contribution to total power output in front crawl is only slightly higher than 10%. Toussaint et al. used the same system to show that propelling efficiency decreases with swimming v (r = -0.84) between 1.05 and 1.3 m/s. The EMG validations of the ‘MAD-System’ (Clarys et al.) and tethered swimming front crawl (Bollens et al.) were also provided. Consequently, the relationships between stroke frequency, tethered force and EMG, found by Cabri et al., gained increased relevance for front crawl performance analysis.

Using inverse dynamics from the IVV curve, Van Tilborgh et al. calculated the resultant impulses per phase of the breaststroke technique, emphasizing the importance of body undulation in this technique. This was one of the few studies of this volume centered on IVV assessment. However, this parameter was the basis of a historical paper on swimmer training and advice (Persyn et al.), integrated with force and performance analysis. The authors also found higher propulsive drag than lift components in each phase of the freestyle arm-stroke cycle, concluding that a quasi-static approach to the hydrodynamics of P in swimming seems to be insufficient. In parallel, Shleihauf et al. went even deeper in the quasi-static propulsion theory, and provided evidence of four propulsive phases in backstroke arm action. Concerning D, the ‘MAD-System’ was referred to in the series for the first time. A very creative use of the device allowed Hollander et al. to show that the leg contribution to total power output in front crawl is only slightly higher than 10%. Toussaint et al. used the same system to show that propelling efficiency decreases with swimming v (r = -0.84) between 1.05 and 1.3 m/s. The EMG validations of the ‘MAD-System’ (Clarys et al.) and tethered swimming front crawl (Bollens et al.) were also provided. Consequently, the relationships between stroke frequency, tethered force and EMG, found by Cabri et al., gained increased relevance for front crawl performance analysis.

Medical contributions were mainly restricted to the analysis of chronic injuries related to swimming sports (Mutoh et al.), or partially hidden by their common physiological (Cazorda et al.; Nomura; Treffene), biomechanical (Schleihau) or EMG (Olbrecht and Clarys) content. However, physiology and thermoregulation presented relevant and innovative contributions (Chattard et al.; Craig; Nielsien; Nováč et al.; Zeman et al.). Decisive, also for its rarity as a longitudinal design, and for the preservation of the Swedish tradition in this regard, was the five year follow-up physiological study of Gullstrand and Holmér. Lavoie et al. presented the backward extrapolation method for the assessment of VO₂ in swimming reducing the mechanical constraints imposed by masks and tubes.

BMS VI (1992)

The theoretical increase of SL with efficiency and power output, and decrease of drag and stroke frequency (Toussaint), allows retaining this parameter as a measure of swimming proficiency. This is, perhaps, one of the reasons why several papers were devoted to stroke parameters and competition analysis (Keskinen and Komi; McArdle and Reilly; Wakayoshi et al.; Witz et al.). Propelling and mechanical efficiencies were also specifically addressed (Cappaert et al. a, b), although a swimming economy profile was criticized as a swimming skill measurement (Chatard et al.). One of the factors already theoretically associated with efficiency is the IVV, a topic that regains its traditional importance in this volume (Chollet et al.; Hahn and Krug; Manley and Aha; Mason et al.; Persyn et al.; Tourny et al.; Ungerechts). Ungerechts, Persyn et al. and Mason et al. used videogrametry, but both Manley and Aha, and Hahn and Krug used the swim-speed-recorder technology, based on an impeller attached to the swimmer’s body to monitor swimming velocity, and Chollet et al. used a more conventional cable speedometer. Two most relevant conclusions emerged from these studies: (i) most of the breaststroke studies revealed a two peak IVV profile, and (ii) IVV tends to reduce with mean velocity, including the number of velocity peaks per stroke.

EMG was also a very relevant topic in this volume covering issues like effects of front crawl speed (Rouard et al.), paddle swimming (Montelle and Rouard), swimming fins (Cabri et al.), water polo (Clarys et al.) and Synchronized swimming (Zinzen et al.).

Physiological contributions were many; they were focused on pure swimming but also on water polo (Hohmann and Frase) and life saving (Daniel and Klauck). Particular emphasis was given to lactate metabolism and testing (Kelly et al.; Keskinen and Komi; Olbrecht et al.; Peyreburn and Hardy; Roi and Cerizza). However, it should be underlined that also much attention was dedicated to the study of the aerobic and anaerobic contributions to different training sets and performances, and its variation with work / rest ratios (Trupo et al.), age and performance level (Takahashi et al.).

Of particular interest was the attempt to match anthropometrical and technical profiles (Colman et al.) relating physical characteristics and undulation in breaststroke, as well as to establish a psychological profile that predisposes for swimming performance (Stallman et al.), considering self-control and motivation, both for training and competition.

BMS VII (1996)

Energy related biomechanical factors were at the centre of this BMS volume. Sanders (a, b) provided evidence supporting the idea that body undulation may contribute to increased propulsion and/or reduced drag, while Vilas-Boas and Alves et al. provided evidence of the relationship between energy cost and IVV in swimming, respectively for breaststroke and backstroke. Moreover, Vilas-Boas found that flat breaststroke was more economical than undulating variations, contradicting the tendency, at the time, to emphasize body undulation. Convergently, Cappaert et al. stated that top breaststrokers are characterized by lower IVV than their lower performance counterparts, and emphasized that higher level Olympic butterfly swimmers show lower trunk angulation to the horizontal. Cappaert, however, wasn’t able to find any correlation of the segmental and full body angular momentum around the CM with swimming performance in a sample of 8 breaststrokers. Energy was also the focus of other contributions, namely considering sprint swimming metabolism (Ring et al.), aerobic/anaerobic energy partition during a 400m freestyle event (Nomura et al.) and energy expenditure during heavy training and taper (Trappe et al., Van Heest).

Wakayoshi et al. provided another contribution explicitly relating physiologic and biomechanical parameters during swimming. They found an interesting coincidence between the OBLA intensity and a “biomechanical turning point”, where SL decreases and SR increases are observed during an incremental front crawl test (SL drop).

Swimming propulsion continued to be addressed. Berger et al. compared propulsive forces measured through the MAD-System and a Shleihau-like quasi-static approach. The MAD-System underestimated the quasi-static effective propulsive force by about 15%. Rouard et al. studied the time duration and the impulse of the different P force components in each phase of the freestyle arm-stroke cycle, concluding the non-existence of significant correlation between these variables and performance. The authors also found higher propulsive drag than lift impulses throughout the stroke.
Critical tethered force (Ikuta et al.) and critical swim-bench power (Swaine), as well as EMG (Monteil et al.) and electrical stimulation (Pichon et al.) were also the object of analysis. Moreover, analysis of training contents and consequences (Mujika et al. a, b), as well as an analysis of the effect of sea-level altitude exposure to altitude acclimatized swimmers (D'Acquisto et al.), were also included.

BMS VIII (1999)

Volume eight is characterized by an increased number of papers that allow diversification of topics and approaches, including a full section devoted to pedagogy, where new questions were considered, like the development of interactive software to teach diagnosis and advice of swimmers (Persyn and Colman). New topics also included: mechanical accelerometry to characterize arm-stroke kinematics (Ichikawa et al.; Ogih et al.); the effect of breathing actions on swimming kinematics (Alves et al.; Barbosa et al.); the effect of body position (prone and supine) on the underwater undulatory swimming technique (Arelanno et al.); the comparison of pool and flume swimming (Wilson et al.); the analysis of the effect of swimming-lane separation ropes on the wave dissipation effect (Togashi et al., Fujishima et al.); measurements of nasal pressure (Hara et al.), and mono-fin force production analysis (Rejman).

The coordination of swimming actions (Chollet et al.; Hohmann et al.; Soares et al.) as well as the IVV (Fujishima and Miyashita; Kolmogorov and Lyapin; Martins-Silva et al.; Reischle) continue to be relevant issues. In this latter domain, the mathematical model of Fujishima and Miyashita allowed further understanding of the inertial effect of IVV over the power dissipation and the mean velocity attained by the swimmer. They didn't consider, however, the added mass effect of the water, a topic that Klauck, Kolmogorov and Lyapin, and Colman et al. addressed. Klauck arrived at a value of 300 to 700 N for towed subjects in an extended prone position (1 to 1.6 m/s), while Kolmogorov and Lyapin reported values of 85 to 100 N for front crawl swimmers at 2 m/s. Both outcomes suggest the need for further development in this field.

Cappaert and Van Heest showed that the maximal values of angular momentum obtained during a front crawl stroke cycle around the longitudinal axis (body-roll) and the sagittal axis (body lateral sway) correlates with energy cost. The effect of body-roll on the insweep hand velocity was revisited by Payton et al., this time using an empirical approach. Results were in opposition to those obtained with the model published in BMSVII: body-roll didn't contribute to the hand velocity during the insweep.

Hydrodynamics (both propulsion and drag) was also a central topic of BMSVIII. Vortex propulsive forces were analysed (Colman et al.; Ungerechts et al.), despite not providing yet a consistent empirical basis for measuring their contribution. On the contrary, the estimation of propulsion based on hand pressure differences (Takagi and Wilson) allowed results underestimating, but highly consistent with external loads supported during sculling motions. Drag was analyzed and compared both in passive and active conditions (Shimonagata et al.; Strojinik et al.). Active drag was measured using a similar approach to the classical velocity perturbation method. Once this method is based on the assumption of constant maximal power output, Strojinik et al. tried to correct the data for the measured power changes, arriving at variations of more than 200% in the final result. They concluded that the method is inappropriate. Lyttle at al. analysed the effect of the glide depth (surface, 0.2, 0.4, and 0.6m) on passive drag at velocities ranging from 1.6 to 3.1 m/s. Their findings showed that gliding at the surface (the dorsum of the swimmer breaking the water surface) caused significantly higher drag values at all velocities, and that 0.4 m seems to be optimal depth required to minimize D.

Coaching and training effects were analyzed. Attention was paid once again to the effect of different combinations of work to rest ratios (Shimoyama and Nomura; Wakayoshi et al.). Interval hypoxia (Bulgakova et al.; Ogita and Tabata; Volkov and Smirnov), and altitude training (Nomura et al.) were shown to enhance anaerobic training load and effects, but not producing significant differences in aerobic performance related parameters (OBLA and VO$\text{max}$).

In the "Exercise Testing" section emphasis was given to the "critical speed" concept (Fernandes and Vilas-Boas; MacLaren and Coulson; Matsumani et al.) showing that it can be used to monitor changes in the training status, inclusively of juvenile swimmers, being strongly related to 4mM velocity (r=0.82) and OBLA intensities (r=0.81). Keskinen and Keskinen revisited the study of the kinetics of SL with swimming intensity, reinforcing the idea of Wakayoshi et al. (BMS VII) that the SL drop point may be a good predictor of the ability to swim long distances at sub-maximal intensities.

BMS IX (2003)

Contrary to BMS VIII, this volume includes a considerable number of papers on start (6) and turn (3) analysis. Emphasis was given to the kinematical, but particularly to the dynamics of swimming turns (Daniel et al.; Roeseel). Goya et al. didn't analyze the turning action, but simply the push-off from the wall, and the subsequent gliding phase. They found similar curves to those observed by Daniel et al., but significant differences between top and trained swimmers both in intensity and duration. Where starts are concerned, the main topic was the comparison of different techniques, particularly the grab start (GS) and the track start (TS) (Issurin and Verbitsky; Krüger et al.; Vilas-Boas et al.). Issurin and Verbitsky analysed the reaction time and the time to 15m during the Sydney Olympic finals, and found evidence in favor of the TS although the GS was more used. Vilas-Boas et al. involved both kinematics and dynamometry to compare the same techniques, but dividing the TS into its two variants (forward - TRF - and rearward projection - TSR - of the CM). They found the GS faster in the reaction time. The GS also allowed a higher impulse than the TSF, but lower than the TSR. All the observed aerial differences vanished when the glide phase to 6m was considered. De la Fuente et al. also examined the importance of the water phase of the starting action. EMG analysis of the start was added by Krüger et al. They found that the faster technique to the 7.5 m mark was the GS, characterized also by higher impulse, and a significantly different muscular recruitment pattern compared to TS.

Coordination of technical movements was approached by different authors (Alberty et al.; Boulesteix et al.; Chollet et al.; Mauro et al.; Potdevin et al.; Schnitzeler et al.; Seifert et al.; Takagi et al.) in the four swimming techniques, and related both with fatigue, IVV, race-pace in competition events, breathing and non-breathing crawl technique, SR, gender, level of performance, use of wet suits, and conventional and unconventional techniques. The evidence provided by Alberty et al. is interesting to note, that the coordination of front crawl changes with fatigue, but not IVV. This latter parameter was used for different purposes: (i) to analyze hydrodynamic concepts of swimming propulsion (Persyn et al.); (ii) to provide evidence on non-stationary swimming mechanics based on hip kinematics (Ungerechts et al.); (iii) to compare the kinematics of the hip and the CM in butterfly (Barbosa et al.); (iv) to analyze time-space factors determinant of the CM kinematics in breaststroke (Silva et al.; Soons et al.); (v) to directly monitor hip velocity examples of the four strokes in a flume (Buckwitz et al.); (vi) to compare the swimming technique of children and adult swimmers (Kjendlie et al., a), and (vii) to analyse the effect of wearing a breathing snorkel (Kjendlie et al., b).

Bideu et al. proposed a device that can monitor IVV, but also can resist swimming progression with a controlled and constant load. With this device, authors were able to revisit the "velocity perturbation" active drag measurement method without the limitations associated with the variability of the drag opposed to the towed device.

Arelanno et al. characterized the underwater butterfly kicking of elite and age-group swimmers using several kinematical variables, including the Strouhal number (Sh). Ito and Okuno returned to Schleichau's model of swimming propulsion, concluding that swimmers should drive the hand backwards along the longitudinal axis of the body to maximize propulsion, and that they need to favor sculling actions when maximum
swimming economy is required. More fundamental research was provided by Klauck, who developed a forward dynamics model to predict swimmer’s velocity on an “if/what” basis.

In this volume, the concept of Critical Velocity, and associated parameters, were revisited (Clipet et al.; Dopsaj et al.; Ogita and Miyashita; Rodriguez et al.; Soares et al.; Takahashi et al.; Wakayoshi and Ogita), but with particular emphasis on their possible contribution to the assessment of anaerobic components of swimming performance. The SL drop intensity was, once again, sustained as a valuable indicator of relevant aerobic training intensities (Dekerle et al.; Nomura and Shimoyama). More direct approaches to this domain included VO2, kinematic (Baron et al.; Fernandez et al.; Ogita et al.; Rodriguez and Mader; Rodriguez et al.), and assessment methods (Cardoso et al.), among other relevant metabolic parameters, opening new perspectives on the importance of O2 metabolism for swimming training and performance. In the mean time, Strumbelj et al. provided evidence that maximal [La] and minimal pH values do not differ between maximal efforts from 100 to 400 m performed by 200 to 400 m specialists, underpinning the importance of both aerobic and anaerobic metabolism in swimming.

Psychological aspects of swimming were also considered (Sugano et al.; Vikander and Stallman; Zientek), as well as talent selection (Bügner and Hohmann; Sawedra et al.) and the influence of maturation, training and competition on the evolution of swimming performance (Helland et al.).

BMS X (2006)

In the last volume of the BMS series, some new research interests and methods were included, particularly relevant in the hydrodynamics domain. “Particle Image Velocimetry” (PIV) was introduced (Kamata et al.); Matsuchi et al.; Miwa et al.; Yamada et al.) as a technique of flow visualisation and quantification (applied to mono-fin, sculling, butterfly kick and hand movement during front crawl). Results support previous assumptions about the importance of unsteady flow to swimming propulsion, and practical consequences were extracted (Ungerechts and Klauck). The introduction of “Computational Fluid Dynamics” (CFD) approaches into the series also distinguishes this volume (Lyttle and Keys). These authors studied the underwater kicking action, showing that large and low frequency kicks seem to be better than small and high frequency ones. Experimentally, Gavilán et al. further concluded that the waving energy transfer along the body starts from the hips, and that the upper body is mainly a stabilizer. The same problem was addressed by Sugimoto et al., who used the computer model proposed by Nakajima to estimate the propulsive action of each body part during underwater dolphin kick. Toussaint et al. reported very high front crawl propulsive efficiency values at also high swimming velocities. They considered that the arm rotation and the associated axial flow possibly established at very high velocities allow bringing added water mass to the propelling segments, enhancing efficiency.

Another area of great interest in this volume was the movement coordination, reinforced by efforts on pattern recognition (Oghi; Oliveira et al.), that allow fast video-based evaluation solutions and feedback (Soons et al.). Chollet et al. analysed the effect of technical mistakes in backstroke coordination, and Schnitzler et al. (a) studied the stability of coordination during maximal and sub-maximal swims. Seifert et al. (a) compared objective (kinematical parameters obtained from digitalization) and subjective approaches (based on expertise), to assess stroke phases in coordination studies. A similar interest was shown by Schnitzler et al. (b, c) who used mechanical velocimetry to increase the capacity to discriminate the propulsive phases during one stroke cycle in order to empower traditional coordination analysis. Tella et al. also combined IVV, coordination and fatigue studies, and found that IVV empowers the understanding of the coordinative changes that occur with fatigue.

IVV and acceleration were again a central topic of research. Mechanical velocimetry was used by Craig et al. and other authors. Using this method, Pedersen and Kjendlie reported significant reductions in the mean maximal velocity when breathing every cycle, compared with controlled breathing. Soares et al. used the IVV frequency spectrum to analyze changes in the mechanical output profile during a maximal 50 m test, presumably allowing the evaluation of “energetic dominancy transitions” relevant for speed training. CM and hip IVV were compared (Capitao et al.; Morouço et al.), being considered to provide similar patterns, and Barbosa et al. analyzed the relationship of IVV of the CM to energy cost of swimming considering the four competitive strokes, and controlling the velocity effect.

Fatigue was explored through an EMG frequency spectrum decrease during an exhaustive 4 x 50 m front crawl test (Cayt et al.). Further use of EMG was proposed by Hohmann et al. to analyse the backstroke start technique to which Krüger et al. added kinematic and kinetic parameters. Takeda and Nomura compared the GS and the TS analyzing the take-off velocity and its extensional and rotational components, underlining the importance of the rear leg action during the TS. Seifert et al. (b) also analyzed starts, but for breaststroke events, considering the coordination of the actions during the underwater cycle. This was the main discriminating parameter of an Olympic breaststroke medalist after the admittance of the butterfly kick. Turns were studied by Pereira et al. using kinematical and kinetic variables. As expected, peak normalized horizontal force exerted on the wall was determinant for performance. Prinz and Patz also studied the flip turn, analyzing the effects of the tuck index, the depth of the wall contact, and the contact time on the velocity of push-off.

Pedagogical and didactical aspects of swimming also received a deeper analysis in this volume. Havriluk measured the effects of an instructional intervention of one week duration on swimming technique using biomechanical parameters such as hand force to time curves and active drag. The main effects were observed on drag. Different instructional programs were also compared (Invernizzi et al., a, b), including heuristic and analytical approaches. Heuristic approaches were shown to be preferable.

Critical velocity and critical power concepts were once more investigated (Dekerle et al. a, b; Filipatou et al.; Greco et al.), inclusively based on reduced distances (Thanapoulos et al.), and applied to define training sets for velocities above the anaerobic threshold (Wakayoshi et al.). Reis and Alves showed that critical velocity and V4 changes similarly with training for age group swimmers. To further analyze metabolic transition zones, the anaerobic ventilatory threshold (Moriais et al., a) and the VO2 at the lactate threshold (Moriais et al., b) were studied. In the same perspective, Machado et al. proposed a mathematical based method to assess the individual anaerobic threshold, and Kjendlie and Stallman verified the validity of non-paced tests for the same use. Complementarily, Shimoyama et al. observed that OBLA changes are mainly determined by physiologic rather than biomechanical factors. VO2 and other respiratory, ventilatory and cardiological relevant parameters were analysed (Fernandes et al., Machado et al., Madeira et al., a, b, Querido et al., Strumbelj et al.). The effects of using a respiratory snorkel on the breathing frequency in front crawl were also studied (Kapus et al.). Physiological (VO2max, vO2OBLA, [La]max) and biomechanical (active drag, maximal propulsive power) characteristics of an Olympic female gold medalist were provided by Ogita et al. and compared with elite college swimmers. The results showed that it was not the physio logic parameters that distinguished the Olympic champion, but a slight drag reduction observed at high swimming velocities, emphasizing the relevance of the biomechanical factors to excel in swimming.

Specific training modes also attracted attention. Peaking and tapering (Iosurin et al.), altitude training (Marcadé et al.), assisted (Preto et al.) and resisted (Llop et al., Mavridis et al.) training were addressed.

Water-polo was extensively studied (Bratusa and Dopsaj; Bratusa et al.; Dopsaj et al.; Klauck et al.; Platonou et al.; Scharn and Strojančik), but also life-saving (Juntunen et al.), triathlon (Bernavent et al.), water running wearing wet vest (Stallman et al., a, b), and synchronised swimming (Homm and Homma, a, b; Ito) were considered. Ito anal-
ysed, in a wind tunnel, five different configurations of the hand considering their hydrodynamic behaviour. It was found that a cupped hand is better than a flat one, but with straight and closed fingers.

Medical and rehabilitation topics were not so abundant in BMS X, but did include very relevant issues like muscular imbalance (Becker et al.), injury incidence (Haupenthal et al.) and the incidence, consequences and strategies facing the detection of Auxiliary Arch of Langer (Clarys et al.). Susceptibility to peroxidation of red blood cells in swimmers (Monteiro et al.), effects of exercise on the cross-sectional area of the vena cava (Onodera et al.), and immunological responses to swim training (Teixeira et al.) were also included, as well as nutrition (Soultanakis et al.; Toubekis et al.) and supplementation (Shiraki and Nomura) analysis.

CONCLUSIONS AND FUTURE PERSPECTIVES
Following recent trends, future developments in Biomechanics and Medicine in Swimming probably will lie upon the development of numerical methods and simulations, both for internal (muscular and inter-segmental) and external (hydrodynamic) biomechanics, as CFD already allows. 3D moving models will be included in the simulation studies with capabilities to respect biomechanical redundancy. Detailed and sophisticated experimental approaches will also progress, like the PIV approaches already included in the series in the last issue. These approaches (combining modeling and experimentation) will allow a deeper understanding of P and D mechanisms, including consistent analysis of added mass inertial effects, and possible propulsive repercussions of eventual axial flow over the propulsive segments. Optical fibre and other in-bedded miniaturized sensors, together with nanotechnology contributions will prevail and provide revolutionary contributions for future scientists.

It is possible that ambulatory kinematics will prevail over image/external light based kinematical processing systems. Special garments, made of intelligent textile fabrics will allow both biomechanical and physiologic evaluation and feedback, including in real-time. It is possible that this type of material will allow new developments in the swimwear industry, allowing "exoskeletons" to be circumstantially created during immersion, based on textiles with memory of shape. Training and testing in anaerobic bio-energetic zones will concentrate more research efforts, probably of inter-disciplinary nature. In fact, it is possible to preview that those inter-disciplinary studies, combining the physiological, biomechanical, and psycho-cognitive domains, will provide paramount information for the progress of knowledge in aquatic sports and activities.

Also an increase will be seen in the exchange of methodology and instrumentation between various activity areas and more activity areas will be represented. There may be a shift in emphasis between scientific domains and activities with continued growth of areas previously less well represented. This is in fact, recommended.

REFERENCES:

ACKNOWLEDGEMENTS
Part of this study was supported by grant: PTDC/DES/101224/2008
Applying a Developmental Perspective to Aquatics and Swimming

Langendorfer, S.J.
Bowling Green State University, Bowling Green, Ohio, USA

Most typically in the aquatic field instructors and coaches employ an "error correction model" to view all swimming behaviors. Using a "straw person" approach, clinicians expect all learners regardless of age or skill to swim like an elite adult swimmer. In this approach errors are corrected mainly when external experts such as teachers or coaches expunge those errors using command style direct teaching. In command teaching, a coach verbally describes and then demonstrates the expected "expert" way of swimming followed by identifying the "errors" the learner makes that deviate from the expert model. In contrast, a "developmental perspective" is defined as a view in which one expects and anticipates regular, ordered changes to occur in swimming behaviors across the entire lifespan. From a developmental perspective, changes in swimming behaviour occur as a result of systemic interactions among individual, task, and environmental characteristics as proposed by Newell (1986). For example, this view expects that someone learning to swim on the front gradually and systematically will change the arm, leg, and breathing patterns they use to move through the water because their body size or density changes, or the way they interact with the task is altered. In this paper I provide a conceptual overview that compares and contrasts the developmental and error correction approaches in swimming by drawing upon contemporary thinking in dynamical systems and motor development theory. In particular, I highlight the three essential clinical skills that aquatic clinicians need to possess when using "developmentally appropriate practices" (DAP) (i.e., developmental assessment, individualization of instruction, and developmental task analysis). For each DAP clinical skill, I provide practical illustrations for how these DAP skills apply to learning in aquatics and swimming. I argue that the predominance of the error correction model within swimming and aquatics has severely limited the field's acceptance and use of best instructional, learning, and assessment practices as well as unnecessarily constrained thinking about swimming skill acquisition in ways that acceptance of a developmental perspective would remedy.

Keywords: swimming skill acquisition, developmental perspective, developmentally appropriate practices, developmental task analysis

INTRODUCTION

Virtually all authors and practitioners in the aquatic field approach the acquisition of skill from what is known as an "error correction model." From this ubiquitous "error model," practitioners view swimming skills from an "all or nothing" perspective in which they expect a single "correct" way of performing each aquatic skill. Regardless of a swimmer's age, skill level, or ability, or the task goal and environment, instructors presume the "right way" to perform any aquatic skill is to match the way a hypothetical elite adult swimmer would perform it.

Because of the presumption under the error model that there is a single right way to perform a skill, the aquatic skill acquisition process becomes one of expunging errors. Expunging errors mainly creates a negative, or "glass-half-full," approach especially for young, inexperienced, or differently-abled learners. The primary view is that these individuals are wrong in how they are trying to swim. Even if they make a single change, they are still not swimming the "correct" way which can be quite frustrating for a young or inexperienced learner. The error model also tends to engender a single direct pedagogical approach, often called "command style," or "tell-show-do," teaching (Mosten, 1966).

This paper proposes that an alternative way of viewing skill acquisition known as the developmental perspective provides a number of advantages to both practitioners and learners. Under the developmental perspective practitioners presume that all voluntary motor skills including swimming skills change gradually over time as a result of a number of complex interactions among individual learners, tasks being learned, and the environmental context. As a more positive and hopeful means of promoting skill acquisition, the developmental perspective understands that motor skills may take on a variety of coordination patterns. These different patterns are acquired in a regular, but gradual, sequence of changes. Developmentally, the different patterns are not viewed as right or wrong, or correct vs. incorrect, but only as less or more developmentally advanced along a developmental continuum as illustrated in Figure 1.

![Figure 2](source)

**Figure 2.**

In facilitating learning, the developmental perspective encourages practitioners to use a much more diverse set of learner-centered teaching and learning approaches instead of just the direct command style implied by the error model. For example, instructors may use indirect teaching-learning approaches such as movement exploration, guided discovery, or task setting (Mosten, 1966). The developmental perspective also provides the opportunity for more diagnostic and prescriptive formative assessment to individualize their teaching (Langendorfer & Bruya, 1995).

METHOD

I argue in this paper for the wider adoption of the developmental perspective over the error correction model in the teaching and coaching of swimming, water safety, and aquatic skills. My argument is not based upon a single empirical study, but draws upon a variety of existing developmental studies and expository articles, both terrestrial and aquatic, that contrast with the observed weaknesses of the error model. I also propose applying several unique developmental approaches to the aquatic field as a means for expanding the repertoire or tool box skills of aquatic practitioners.

The first unique element that has not previously been applied to aquatics is Newell's (1986) constraints model. The constraints model draws upon contemporary dynamical systems theory. Newell (1986) uses a triangle as a simple metaphor to portray how swimming coordination patterns may vary according to relationships, called constraints, among an individual, the task goal, and environmental context (see Figure 2). For example, as an individual swimmer grows or gets stronger, the way she swims a front crawl (or freestyle) stroke gradually changes the arm pull, leg kick, or body position because her size and fitness enable her to interact within the water environment differently than when she was smaller and less fit. Similarly, the constraints model proposes that if an instructor alters characteristics of the front crawl stroke (e.g., how far, how fast; added buoyancy), the crawl pattern also may change. Teaching can influence the swimming skill not because the swimmer does what a teacher demonstrates or instructs, but because the instructor manipulates the task goal (e.g., speed, stroke length) or characteristics of the environment (e.g., water temperature, depth).

Developmental level of movement

Device

Individual

Task

Environment

A second unique element to apply to aquatics is a concept called developmentally appropriate practices, also known as DAP (Bredekamp,
1987). I propose for our purposes that we modify this concept and call it DAAP, or developmentally appropriate aquatic practices, to emphasize how we can apply this early childhood educational concept to the teaching-learning of aquatics across the lifespan.

Robertson (1993) proposed that we should define DAP as the process of identifying where an individual falls along a lifespan developmental continuum and matching tasks to the needs and readiness of each individual. In order to accomplish Robertson’s definition of DAP, she suggests that practitioners need to acquire three distinct developmental skills. Practitioners need 1) to possess developmental assessment skills by using developmental sequences, 2) to appreciate how to individualize instruction, and 3) to know how to make tasks easier or harder, depending upon the needs of the individual.

**Developmental assessment.** Employing developmental aquatic assessment skills requires practitioners to reject the error correction model assumption that there is one correct way to perform a skill and appreciate that all swimming skills change in regular, ordered sequences. Several developmental aquatic assessment instruments have been published (Erbaugh, 1978; Langendorfer & Bruya, 1995). They represent using aquatic developmental sequences to identify where along a developmental continuum a swimmer’s skill or stroke falls.

**Individualizing instruction.** Individualizing how one provides instruction requires a shift away from the traditional “one-size-fits-all” teacher-centered techniques to focusing on the needs of each learner. Learner-centered teaching focuses on helping each swimmer to move from where she is to being more advanced. Generally, this means that a practitioner needs to employ more indirect teaching techniques such as exploration, guided discovery, or task setting (Mossten, 1966). It also requires the use of developmental assessment to determine each swimmer’s developmental level.

**Making tasks easier or harder.** The third developmental skill for structuring an appropriate aquatic environment is the recognition that, in line with Newell’s (1986) constraints model, task performances change according to their relationship to the complexity of the task. One very simple means for systematically varying task complexity uses developmental task analysis, or DTA (Herkowitz, 1978; Morris, 1976; Robertson, 1989). One variation on DTA includes constraints-based task analysis (Haywood & Getchell, 2009). Each of these techniques create a structure by which task factors can be systematically altered as the primary means for changing the coordination patterns of aquatic skills (see Table 1).

### RESULTS

In this section, I provide several explicit examples of how to employ Robertson’s proposed skills for DAAP within an aquatic instructional program to facilitate optimal learning under a developmental perspective. In doing so, I reference Newell’s constraints model and one version of an aquatic DTA. Where appropriate, I contrast how the developmental perspective differs from the error correction approach.

I propose to use a hypothetical example of a mixed age (from 7 to 20 years old) class of 15 swimmers who all desire to learn how to swim front crawl stroke. I also want to illustrate the common fallacies associated with extreme age differences to illustrate how DAAP should work regardless of the height of each individual, in not absolute distance units such as centimeters or meters.

<table>
<thead>
<tr>
<th>Table 1. A proposed aquatic developmental task analysis.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Swim Factors</strong></td>
</tr>
<tr>
<td>Complexity</td>
</tr>
<tr>
<td>Easy (simple)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Hard (difficult)</td>
</tr>
</tbody>
</table>

### DISCUSSION

I propose that my hypothetical class in which learning to swim front crawl stroke is approached from a developmental perspective and employing the three D.A.A.P. skills proposed by Robertson (1993) appears to be rather different in a number of ways than a similar class organized according to an error correction model. Those ways include the use of formative assessment, I.A.E.P.s, need-based lesson planning, individualized learning stations, and structuring learning tasks using aquatic developmental task analysis.

Under the typical error correction model, assessment is primarily summative in nature. It typically occurs during the final session, not the first session. When it does occur formatively, feedback is in the form of the "errors" that the swimmer is committing, not diagnostic corrective feedback about what the swimmer already can do and what s/he needs to do next. The I.A.E.P. allows the formative assessment using the ARA to be translated individually for each class member and allows them to work on the specific developmentally appropriate next levels. The learning station approach employed in my hypothetical class is learner-centered and allows each member to take responsibility for her
or his own learning while the instructor serves as a facilitator, not the primary instrument for demonstrating the right way to perform each skill. Each individual can work on those skills that they should master next. In contrast, a typical error model class would all be working on the same skills regardless of their individual needs.

The presence of aquatic DTAs allows both swimmers and instructors to create a multitude of learning activities that they might otherwise not create without a DTA. It is noteworthy that the relatively simple DTA in Table 1 with only 5 factors each with 3 levels of complexity allow 243 different and unique learning situations that few if any instructors might create under an error correction model.

CONCLUSIONS
This paper compares and contrasts the developmental perspective with a more typical error correction model, identifying significant ways that developmentally appropriate practices can individualize acquisition of swimming, water safety, and aquatic skills. It introduces Newell’s (1986) constraints model and Roberton’s three DAP instructional skills required of swimming practitioners for employing a developmental perspective.

REFERENCES

The Psycho-Physiology of Overtraining and Athlete Burnout in Swimming

Lemyre, P.-N.

Norwegian School of Sport Sciences, Oslo, Norway

Understanding swimmers’ response to training and competition continues to be a significant challenge. Although a great deal of research has previously attempted to better understand the psychological and physiological factors leading to maladaptive training responses in an elite swimmer population, very few attempted to integrate these two fundamental perspectives. Therefore, the aim of this study was to investigate the relationship between personal dispositions, contextual motivation factors, subjective performance satisfaction, hormonal variation and burnout in elite swimmers. 53 elite swimmers (F=21, M=32) participated in a protocol of 6x200m progressive intervals during morning (07.00-08.30) and afternoon (14.00-15.30) training sessions. Venous blood was drawn before and after each set of intervals and was analyzed for adrenocorticotropic hormone (ACTH) and cortisol by radio immune assays. This protocol was used at three time points during the season, corresponding to the easy, very hard and peaking time periods of the swimming season. Questionnaires assessing psychological variables were used together with the two-bout exercise test at three time points during the season. Using hierarchical regression analysis, results indicated that variation in basal cortisol (15%), maladaptive perfectionism disposition (20%), perceived mastery motivational climate (12%) and subjective performance satisfaction explained together a total of 67% of the variance in athlete burnout at season’s end. Hormonal monitoring is costly and invasive, current findings support the initial use of psychological monitoring, while hormonal monitoring may be used as a second step to help athletes steer away from maladaptive training outcomes such as athlete burnout.

Key words: overtraining, burnout, prevention, hormones, motivation

INTRODUCTION
Elite swimmers are exceptionally gifted individuals born with the physiology to excel in their respective discipline. Typically, they are highly motivated and dedicated to training and reaching very high goals. This determination helps them persevere through the most demanding workouts and survive harsh training conditions. These qualities and the high commitment involved in being a high performing swimmer have raised these swimmers to the level of elite performances. How- ever, when facing frustrating setbacks, the same exact qualities that have elevated them elite performance may become their worst enemies and lead to overtraining (Hall, Cawthraw, & Kerr, 1997). Resulting in long term decrement of performance capacity, an overtraining state originates from a long lasting imbalance between training and recovery. Restora- tion may take several weeks or months (Keider, Fry, & O’Toole, 1998). After some time, swimmers may get used to the new state of tiredness and adjust to feeling tired all the time. Elite swimmers experiencing enduring physiological and/or psychological exertion, without significant recovery or achieving the desired goal, may develop athlete burnout. Burnout has been defined as a state of mental, emotional, and physical exhaustion (Freudenberg, 1980) brought on by persistent devotion to a goal, without recognizing the need to recuperate, in the quest for a goal that may be opposed to reality.

Recently, as inter-disciplinary research has taken a closer look at ath- lete burnout, some researchers (Gould, 1996; Hall & al., 1997; Lemyre, Hall, & Roberts, 2007) have suggested that "motivation gone awry" may play an important role in the onset of burnout. The focus of the present research is to investigate this hypothesis. We adopted contemporary social-cognitive motivational theory as our conceptual base for this study. From a motivational viewpoint, it is clear that swimmers have many
different achievement goals; two main goals have been identified and found to operate in the social context of sport, namely a task goal orientation and an ego goal orientation (Roberts, 2001). When the swimmer adopts a task oriented goal, success and failure are judged by whether one has mastered the activity, improved at the task or met self-imposed standards. When the swimmer adopts an ego oriented goal, success and failure are judged by whether one demonstrates normative ability and avoids demonstrating comparative inability. The way a swimmer defines success influences the level of self-determination they experience in the sport. When success is task oriented it is argued that the swimmer is intrinsically motivated. The activity is freely experienced, self-endorsed, and the locus of causality is perceived as internal (Deci & Ryan, 2000). However, some actions can be motivated by external sources of control that are not endorsed by the self. Both personal dispositions and situational factors (e.g., motivational climate) are presumed to affect the motivational state. Behaviors are extrinsically motivated when external sources of control are perceived. Within Self-determination theory, extrinsic motivation is multidimensional and consists of three different types of motivation presented on a continuum going from lower to higher levels of perceived locus of causality or self-determination: external regulation, introjected regulation and identified regulation. Finally, swimmers may be amotivated when they do not perceive contingencies between their behavior and outcome, the action is perceived to be out of their control even though they may continue to participate.

It has been suggested (e.g., Silva, 1990) that though psychological processes underpinning athlete burnout are important, the phenomenon occurs only when these psychological processes are combined with negative training adaptation. Sustained failure to adapt to training generates excessive fatigue. Training when the body’s adaptivity is lost, leads to overtraining (Silva, 1990; Urhausen, Gabriel & Kindermann, 1998) and increases vulnerability to athlete burnout (e.g., Lemyre, Roberts, & Stray-Gundersen, 2007). Athletes, then, suffer from a neuroendocrine imbalance and typically experience a noticeable drop in performance. Research findings (e.g., Urhausen et al., 1998; Meeusen, Placentini, Busschaert, Buyse, DeSchutter & Stray-Gundersen, 2004) support that athletes experiencing the overtraining syndrome seem to suffer from a dysfunctional hypothalamic-pituitary-adrenal (HPA) axis response to exercise. This results in an altered hormonal response to intense training and competition. Recent findings (Meeusen et al., 2004) from research monitoring hormonal reaction in athletes using a two-bout exercise protocol, to detect differences in training adaptation status, suggest that hormonal variation witnessed in cortisol and adrenocorticotrophic hormone (ACTH) levels, combined with responses to exercise are indicative of adaptive resources in an elite athlete. Lower ACTH and cortisol responses have been recorded in overtrained athletes.

Cortisol variation represents an important marker of working capacity and performance level (Meeusen et al., 2004) and has been linked to changes in mood, sleep quality, sensory stimuli recognition, and to the extinction of previously acquired habits (i.e., active recovery). Cortisol is also related to many important physiological changes. The hormone is known to suppress the immune system. Because basal cortisol levels represent the endpoint of the HPA axis, it has been suggested that basal cortisol levels may be used for training monitoring (e.g., Urhausen et al., 1998). Higher levels of basal cortisol have been linked to normal stress response to high-intensity training, while a drop in basal cortisol has been used as a marker of overtraining (Lehmann et al., 1993). Using a two-bout exercise test to investigate ACTH as a marker of overtraining and burnout, Meeusen and colleagues (2004) found hyperactivity in the HPA axis during the morning bout followed by a depletion in the ACTH pool (Urhause et al., 1998) for the afternoon test. These findings suggest that a hypersensitivity of the pituitary followed by an exhaustion of resources is to be found in athletes suffering from severe overtraining and burnout. Unfortunately, research efforts investigating training adaptation using cortisol and ACTH as markers have failed to offer a consistent account of the processes involved (for a review, see Viru & Viru, 2001). When investigating pathological training responses found in overtrained athletes, Urhausen and colleagues (1995) identified the inability to sustain intense exercise as an important symptom. Overtrained athletes are believed to be able to perform well at the beginning of a race, or a hard training session, but they experience problems sustaining their normal level of performance or even completing the actual exercise session. From this perspective, recent studies (e.g., Rønset, Haug, Pederson & Bahr, 2001; Meeusen, 2004) have used two consecutive maximal exercise test protocols to investigate training adaptation and maladaptation. They found that beyond the information provided by hormonal responses recorded during the first bout of exercise, the information gathered from hormonal variation during the second bout offered valuable indication of an athlete’s recovery capacity and ability to complete a second bout normally.

When elite swimmers are tired, fatigue may become a trigger for a shift in self-regulation from intrinsic to more extrinsic criteria. For example, Davis, Botterill, and MacNeill (2002) have found that an increase in fatigue levels leads to a neurochemical response producing a series of mood disturbances. It is hypothesized in this study that a recorded shift from intrinsic motivation to introjected regulation may indicate a sign that the swimmer is experiencing significant fatigue. When this happens, it is reasonable to surmise that the tired swimmer functions on automatic pilot, becomes emotionally and mentally more detached from the purpose of quality action and experiences a shift in self-regulation. At this point the swimmer may be more likely to follow a coach’s plan without any questioning or adaptation. In an attempt to better understand the determinants of healthy training response in elite swimmers, the aim of this study was to look at how motivation can go awry and lead to overtraining and burnout. Overtraining and burnout share diagnosis characteristics such as performance loss, fatigue, exhaustion, and mood disturbance (Kenttä & Hassmén, 2002). However, when a swimmer is overtrained, motivation remains, whereas the burned out swimmer experiencing a shift in quality of motivation may devalue sport and express cynicism. Most clinical problems of overreaching and overtraining are observed in swimmers training with a high metabolic load of more than 4,000 kilocalories per day (Steinacker & Lehmann, 2002). Chronic stress and overtraining are expected to cause increases in basal cortisol, which can be interpreted as an indication of metabolic problems. Therefore it is hypothesized that maladaptive motivation shifts, together with variation in basal cortisol in elite swimmers, can better predict overtraining and burnout at season’s end.

METHODS
An elite American collegiate swim team (female=21; male=32) was recruited to participate in this study. Questionnaires assessing motivation were used together with a two-bout exercise test at three time points during the year, corresponding to the easy (September), very hard (November) and peaking time (March) periods of the collegiate swimming season. A protocol of 6x200m intervals during morning (07:00-08:30) and afternoon (14:00-15:30) training practices was used at each of the time points. Venous blood was drawn before and after each set of intervals, as well as the following morning, and was assayed for cortisol by radio immune assays. A sum score for basal cortisol was put together by using cortisol levels for the early morning blood draw, the after noon blood draw before the second exercise bout and the day after morning blood draw. Basal cortisol in November and March were thereafter subtracted from the September score to look at how variation can predict maladaptive training response. In September, achievement goals (POSSQ, Roberts & al., 1998) and quality of motivation (SMS, Pellerier & al., 1997) were measured. Perception of the motivational climate (PMCSQ; Seifriz, Chi, & Duda, 1992) and athlete burnout (ABQ; Raaeleke & Smith, 2002) were recorded in November. Athlete burnout and quality of motivation (SIMS, Strandage & al., 2003) were again recorded at season’s end. Performance markers (improvement in personal bests) and total training loads and intensity were also recorded.
RESULTS
One of the primary purposes of this study was to investigate whether motivation was related to the development of overtraining and burnout in elite swimmers. No significant correlation was found between achievement goal orientations in September and burnout levels at mid-season or season’s end. In contrast, strong correlations were found between perceptions of performance climate on the team and feelings of burnout in November (r = .570, p < .001) and at season’s end (r = .454, p < .001). Significant negative correlations were found between a perception of a mastery climate and burnout in November (r = -.494, p < .001) and at season’s end (r = -.343, p < .01). Significant correlations were also found between levels of external regulation at season start and burnout at the end of the season (r = .290, p < .05). Levels of amotivation at season’s start was highly correlated with levels of burnout in November (r = .516, p < .001) and at season’s end (r = .547, p < .001). When looking at the quality of motivation in swimmers at season’s end, intrinsic motivation was negatively correlated to burnout (r = -.379, p < .01), while external regulation (r = .312, p < .05) and amotivation (r = .340, p < .01) were positively correlated to burnout levels.

Using linear regression analysis, variation in basal cortisol from September & March predicted (p < .05) total burnout in March. Difference in basal cortisol from September & November also predicted burnout in March (p < .05). Variations in perception of a mastery oriented climate (p < .05) and perception of a performance oriented climate (p < .05) in November also predicted levels of perceived emotional and physical exhaustion at season’s end. To further investigate how variation in cortisol can predict burnout, swimmers that were very high or very low on burnout related variables were identified by using scores a standard deviation under and above the mean to divide swimmers in two extreme groups. Using t-tests, significant differences in basal cortisol were investigated for the two groups of swimmers high or low in burnout in November or at the end of the season. High and low levels in perceived exhaustion in November and March were respectively predicted by differences in basal cortisol from September to November (p < .05), and from September to March (p < .05).

DISCUSSION
Findings above support the hypothesis of the study in that it appears that motivation can go awry and contribute to the experience of burnout. Basal cortisol variation as well as a perception of a high performance climate on the team predicted burnout. When the coach emphasizes ego involving criteria then the swimmers experience a shift in quality of motivation toward a stronger extrinsic motivation. This leads the swimmer to follow a coach’s plan without any questioning or adaptation. The shift to a strong external regulation may cause a change in the swimmer’s perception of autonomy and self-determination may contribute to an increase in basal cortisol variation. Enduring high basal cortisol variation is not beneficial to recovery and may lead to overtraining and ultimately burning out. These findings are interesting as they underline the importance of the external factor (motivational climate) on the quality of motivation of a swimmer and a subsequent perception of burnout during the competition season. These results need verification but are potentially important in that they demonstrate that motivational variables are related to physiological variables in the determination of burnout in elite swimmers.

REFERENCES

ACKNOWLEDGEMENTS
I wish to acknowledge the important contribution of Glyn C. Roberts, Darren C. Treasure, Jim Stray-Gundersen, and Kathy Matt to this ongoing project aimed at preventing the onset of overtraining and burnout in elite swimmers.
Biomechanical Services and Research for Top Level Swimming: the Australian Institute of Sport Model

Mason, B.R.

Australian Institute of Sport, Australia

This keynote address paper reviews the Australian Institute of Sport's influence on competitive swimming within Australia. This involves the effective utilising of biomechanical servicing and research tools. The A.I.S. was established in 1981 as a consequence of the nation's poor performance at the 1976 Olympic Games. After its establishment, up to eleven years passed before Australian swimming performances were positively influenced by the efforts of the national sports institute. The early days of the institute involved primarily applied servicing. This later evolved into a greater role for research projects. Most of the early research involved the development of specialised analysis systems which in turn resulted in the capability to carry out more fundamental research. Some of the research projects are discussed within the paper. The main swimming biomechanics research projects initiatives at the A.I.S. are in: drag analysis, start and turn investigations and computation fluid dynamics.

Keywords: Biomechanics, swimming, servicing, research, Australian Institute of Sport

At the 1956 Melbourne Olympic Games, Australia won 35 medals, the third highest number of medals of all nations competing. During the 1960 Rome Olympics, Australia was fifth in the medal tally with 22 medals and in the 1964 Tokyo Olympics, Australia was eighth with 18 medals. By the 1976 Montreal Olympics, Australia had slumped to 32nd in the international medal tally with only 5 medals including no gold. The Australian Institute of Sport (A.I.S.) was established in Canberra during 1981 by the Australian Government as a consequence of several consultancy reports that were completed after the 1976 Montreal Olympics and initiated as a result of Australia’s poor performance in those Olympic Games. These reports indicated that if Australia wanted to regain its sporting eminence, a government funded institute of sport needed to be established to assist in the development of Australia’s elite sportsmen and sports women. By the end of 1982, the A.I.S. had eight residential sports and a sport science medicine centre with all the traditional sport science disciplines represented. However, over these first few years, the services that were able to be provided were split over all sports with only a single scientist in each discipline to provide minimal service for each institute sport.

Competitive swimming is probably Australia’s premier Olympic sport, as this is traditionally where Australia wins most of its Olympic medals. Table 1 provides insight as to Australia’s performances in competitive swimming, before and following the development of the A.I.S. The table also provides a reason for variations to trends over the period in the Olympic medal tally for each Olympic Games.

On observation of the trend in the Olympic swimming medal tally over the period; it can readily be identified that a longitudinal relationship existed between Australia’s Olympic swimming medal tallies at successive Olympic Games and the establishment of the A.I.S. It was also quite obvious that following the establishment of the national sports institute there was a period of 11 years before Australia was able to reap the rewards that resulted from the A.I.S. involvement in the development of Australia’s elite swimming talent.

Table 1. Australia’s Swimming medal tally from the 1956 Olympics to the 2008 Beijing Olympics

<table>
<thead>
<tr>
<th>Olympics</th>
<th>Australian Medal tally</th>
<th>Explanation for Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>1960</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>1964</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>1972</td>
<td>10</td>
<td>Shane Gould = 5 medals</td>
</tr>
<tr>
<td>1976</td>
<td>1</td>
<td>Moscow boycott</td>
</tr>
<tr>
<td>1980</td>
<td>7</td>
<td>A.I.S. Established</td>
</tr>
<tr>
<td>1984</td>
<td>12</td>
<td>Los Angeles boycott</td>
</tr>
<tr>
<td>1988</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

My original appointment in 1982 was as the head of the A.I.S. Biomechanics department. Throughout this early period of about five years, I was responsible for the biomechanical servicing of all the institute sports with only a support officer to assist me. General commercial biomechanics equipment was used in servicing, rather than specialized sport analysis equipment. For swimming servicing, underwater high speed cine film and video was used to capture athlete performance during training and this was used with subjective analysis to assist the coach and swimmer.

During the next five years another biomechanist, a support officer and a technician were appointed to the department. This enabled greater specialization for the servicing of each sport. Each biomechanist now only serviced half the number of institute sports and this resulted in more specialized servicing for each sport. However during this period other sports were also added to the A.I.S. portfolio. Although research projects were infrequently completed to identify solutions to particular problems posed by the coaches, the vast majority of the biomechanics department’s role was directed toward applied servicing. One swimming related research project completed during this period involved the identification of acceleration profiles within breaststroke and butterfly swimming. This research identified a catch the wave phase in these strokes, with the better swimmers more able to utilize propulsion from catching the wave.

More staff were added to the biomechanics department in the early 1990’s, including another biomechanist, several post graduate scholarship holders and another technical officer. This resulted in the formation of biomechanics teams that specialized in the servicing of particular sports. It was during this period that research to develop specialized analysis systems for particular sports, began to occur. In swimming, a large competition analysis system was developed that could analyze many competitors in the one race. The system was initially designed to assist A.I.S. swimmers but toward the mid 1990’s was commissioned by the national swimming body to analyze all swimmers competing in the national championships held each year. This large analysis system was used for analyses during national swimming championships through 2004. Throughout this period the ‘big analysis system’ was continually undergoing refinement and was commissioned by the competition management of swim meets to be used for the analyses of all swimmers in the 1998 FINA World championships in Perth, the 1999 Pan Pacific Championships...
in Sydney, the 2000 Sydney Olympic Games and the 2002 Commonwealth Games in Manchester.

Following the successful analyses of swimmers with the “Big System” during the mid 1990’s and the need for coaches to have similar analysis information available to them between sessions during international competition meets abroad, a portable competition analysis system called SWAN was developed. Each SWAN system could analyze only a single swimmer within each race, but it was portable enough to take overseas with the team. During the late 1990’s and early 2000’s the SWAN analysis system accompanied the Australian Swim team to most international competition meets. Also during this period, the initial development of a start and turn SWAN analysis system was developed to be used in a training environment. The output from this system included underwater visual video images and both timing and force analyses. However, the output for the coach was not in a concise form and was presented in a number of formats including video, hard copy paper print outs of data and hard copy graphs. Probably the greatest barrier to development of advanced analysis systems during this period was the level of technology that was available for inclusion into such systems.

Prior to the Sydney Olympic Games, the A.I.S. sport science and medicine departments provided most of the support to the Australian national swim team. It was also during this period that each of the state government’s state institutes of sport were able to obtain federal funding for elite sports performance enhancement in sports that were analyzed. The procedures developed were able to be used in all of these sports previously provided only by the national sports institute.

In 2006, the A.I.S. embarked on a new concept of directing resources into particular sports, such that the A.I.S. would lead the way in Australia in these sports by concentrating its efforts in set directions. The Aquatics, Testing Training and Research Unit (A.T.T.R.U.) was established in January, 2006 and it operated out of a new 10 lane, three metre consistent depth, 50 metre long technology pool. The A.T.T.R.U. was to work with just aquatic sports and had as its fundamental role the servicing and research for both A.I.S. swim teams and the Australian National swim team. Along with this development was a concentration of biomedical and technology resources into elite Australian Swimming. Initially the research objective of the A.T.T.R.U. was to develop state of the art analysis systems. These systems would operate in a training environment and would provide almost immediate feedback to coaches and swimmers. A system called Wetplate (Figure 1) was developed that provided the coach with immediate feedback analysis of starts, turns and relay changeovers in a concise computer generated visual format. Additional to the Wetplate analysis equipment, was another system designed to look particularly at the free swimming element of the sport. This was the active drag analysis system and provided as feedback to the coach and swimmer, a video image of the swimmer’s actions along with a moving graph of the propulsive force profile generated by the swimmer’s technique.

It became clear for the A.T.T.R.U. at this point in time that the major research focus of the unit was on equipment and system development. This in itself is a legitimate research area as it involves the bringing together of different technologies to produce a system that is able to provide insight into performance enhancement. Such systems are generally not available commercially, so to provide the information to the swimmer and coach there needed to be commercially available equipment, such as Gig E cameras, computers and transducers that when assembled together to form a system were able to provide what was required. The analysis of skills needed pertinent and accurate information concerning the execution of the skill in an immediate time frame. The analysis results had also to be presented in a concise format that could easily be interpreted by the coach and swimmer. The evolution of these systems would result in questions by the coach that would result in more tradition fact finding research projects.

By 2008, the Wetplate and Active Drag Analysis systems were well entrenched into the training program of the A.I.S. swimming squad and were regularly called upon at event camps and national swim team camps. At these camps, Swimming Australia held intensive preparation sessions for elite Australian international swimmers. Because of the vast amount of information provided by the Wetplate system, it took quite some time to identify those parameters and understand the interaction of these parameters, to make a significant difference to improve a swimmer’s performance. Small research projects were at first carried out by the post graduate scholarship holders to do just that. Some such projects involved investigating the propulsive gains to be made by using the new FINA approved starting blocks with the kick plate. It soon became apparent that in order to optimize the learning and performance enhancement potential of the new swim analysis systems, that the swimmer’s coach needed to play a particularly active role with the swimmer during feedback at the Wetplate analysis session. Feedback by the coach was more readily accepted than by the biomechanist, but this model required that the coach understand what was meant by each parameter assessed, understand how each parameter related to performance and be able to provide appropriate information to the swimmer that could readily be adopted and incorporated into the swimmer’s actions during skill performance.

The A.T.T.R.U. also financially supported and accommodated several Ph.D. scholarship programmes in conjunction with an Australian University. In these Ph.D. programmes, part funding came from the A.I.S. while other funding came from the university. These Ph.D. programmes investigated research topics of interest to elite swimming performance. One such Ph.D. project researched methods by which the active drag analysis could be utilized to present the propulsive force profiles of swimmers, in conjunction with video footage of their technique, to identify and eliminate technique inefficiencies for the elite swimmers that were analyzed. The procedures developed were able to be used in all the swimming strokes and resulted in identifying problems associated with such actions as breathing and asymmetry in the swimmer’s technique. In freestyle swimming the active drag analysis procedures were able to identify that most of the propulsive action of the arm during the first half of the underwater stroke was utilized to compensate for the forward movement of the recovery arm above the water. It was the last half the stroke that produced the forward acceleration of the swimmer’s body. The information from the active drag analysis focused upon the total force produced by the entire body as a whole, rather than solely by the arms or legs. Another Ph.D. research project focused upon how best to utilize the new kick plate starting blocks. The Wetplate system enabled the data for this project to be analyzed. Recently, a post doctoral researcher from Ireland was funded by the A.I.S. to work within the A.T.T.R.U. with the objective to analyze the most effective placement of the dolphin kick in breaststroke starts and turns. This research project arose as a consequence of the new FINA rules for Breaststroke.

The A.T.T.R.U. has recently focused upon active drag analysis as
it provides valuable information about the free swimming component of the sport. The mean active drag of a swimmer moving at a constant velocity is equal in magnitude, but opposite in direction to the mean propulsive force produced by the swimmer. The method of active drag assessment, used at the A.I.S., may only be performed at the swimmer's maximum swimming velocity. The assumption made to calculate a value for active drag is that there is an equal power output by the swimmer in both free swimming at the maximum swim velocity and in the assisted condition where the swimmer applies maximum effort to stay with the tow. The method used is similar to the velocity perturbation method (VPM) developed in Russia (Kolmogorov & Duplishcheva, 1992) but instead of resisting the swimmer, the A.I.S. method assists the swimmer by pulling the swimmer through the water at a slightly higher velocity than the swimmer’s maximum swim velocity. However, the value of the mean active drag for the swimmer is only pertinent at the swimmer’s maximum swim velocity. Therefore, the active drag value for a swimmer can only be compared with that of another swimmer if both swimmers had identical maximum swim velocities. If swimmers had different maximum swim velocities their active drag values could not be compared, as velocity plays a major role in the magnitude of the active drag. The question arose, could a swimmer’s active drag be estimated for any given speed if the active drag for the swimmer’s maximum speed was known. Recent research in the A.T.T.R.U. (Mason et al., 2009) that looked at the relationship between active drag and passive drag at the swimmer’s maximum velocity found a very high relationship between the two. The measurement of passive drag can be readily measured at different velocities with little error. The problem that exists is that active drag cannot be measured directly but may be calculated using other indirect measurements which may produce a wide range of values. A research project to investigate whether active drag could be estimated from a force measurement obtained in fully tethered swimming indicated this was not the case (Mason et al., 2009). Therefore, could an equation that represented the magnitude of a swimmer’s passive drag through a range of swim velocities be useful in obtaining an estimation for active drag over a range of swim velocities. The equation for passive drag was established as an exponential equation \( F = a \cdot e^{b(v)} \), where \( a \) and \( b \) are constants for a particular swimmer. A similar exponential equation with a higher value for \( a \) could also be used to represent the active drag of the swimmer over a similar range of velocities. The constant \( a \) (passive) reflects the more innate characteristics of the individual swimmer and their suitability to aquatic motion. The constant \( a_{paa} \) (active-passive) reflects the efficiency of the swimmer’s technique. In both cases, the lower the constant’s value, the better suited the swimmer to aquatic motion or to technical efficiency. The \( a_{paa} \) and the \( a \) therefore provide an index which may be used to evaluate a swimmer’s capabilities. Huib Toussaint spent three weeks as a visiting researcher with the A.T.T.R.U. in early 2009. This was followed later on that year with a visit by A.T.T.R.U. staff to Innsport in Eindhoven. During this visit, an active drag research project was conducted to investigate differences between the A.I.S. method by which active drag is estimated and the measurement of active drag (MAD) method of active drag assessment.

The A.T.T.R.U. has a three year relationship with the mathematical division of the Commonwealth Science and Industrial Research Organisation (C.S.I.R.O.) to develop a system by which computational fluid dynamics (CFD) may be utilized to evaluate proposed changes to a swimmer’s technique in a computer environment, prior to making a physical change in the swimmer’s technique. Physically changing the technique of a swimmer is a difficult and a time consuming process. Even when changes are made, the result may possibly cause a deterioration rather than an improvement in the swimmer’s performance and such a change may not be easily reversed. It makes sense to evaluate the benefits of proposed changes of technique in a computer environment rather than attempting to make physical changes to the swimmer’s technique without such evaluation. The CSIRO are using a CFD pro-gramme which utilizes smooth particle hydrodynamics (SPH) to model the swimmers actions in water. The A.T.T.R.U. have obtained a body scanner to be able to accurately represent the physical characteristics of each swimmer in the CFD computer and are presently attempting to find a reliable method by which the 3D kinematic model of each swimmer’s actions are able to be recorded for the CFD computer programme.

Australian Swimming itself has been organizing competition analysis to be performed at national Championships since 2004. The A.T.T.R.U. is at present building a new portable competition analysis system utilising GigE cameras. It is proposed that the new Platypus system will cut down post analysis processing by a factor of ten and will be able to provide much more accurate data to the coach than the competition analysis systems that are used at the present time.

This paper has attempted to provide an overview of where the A.I.S. is heading in the pursuit of biomechanical systems that will enhance performance and enable quality research to find solutions to questions that are being asked in elite competitive swimming. The paper commenced with a brief history as to why the A.I.S. was established and followed this with where the A.I.S. is moving in an attempt to provide Australian elite swimmers with systems, unique in the world, that will enhance performance in swimming.

REFERENCES
Aquatic Training in Rehabilitation and Preventive Medicine

Prins, J.

Department of Kinesiology and Rehabilitation Science, University of Hawaii, Honolulu, Hawaii, U.S.A.

INTRODUCTION

Aquatic physical rehabilitation is now recognized and utilized as a "procedure," rather than a modality. The increased focus can be attributed in part to its evolution from the limited confines of "Hubbard Tanks," to the larger venues of swimming pools. The larger exercising areas serve as a venue for performing a greater variety of exercises, including those that require sustained propulsive movements.

The physical properties of water provide a unique environment for improving strength, flexibility, and cardiovascular conditioning. Although exercise in the water, including formal swimming strokes have historically been used for the recovery from injury, there is now an increased focus on incorporating specific aquatic exercise protocols for treating persons with acute or chronic clinical conditions, including persons with permanent physical disabilities (Becker & Cole 1994; Cole et al. 2004; Genuario & Vegso 1990; LeFort 1994; Prins & Cutner 1999; Thein & Brody 1998).

OVERVIEW AND PRECAUTIONS

As a rule, voluntary movements in the water are viewed as "learned skills" requiring instruction and taking time to develop. Furthermore, kinesthetic feedback provided by the water is subtle, and therefore, effective movement patterns need to be practiced and closely monitored.

A person who has previous aquatic experience may be expected to begin aquatic physical therapy with less apprehension than someone unfamiliar with the water. However, past experience can be an impediment to recovery because there remains the risk of "overuse" or in the case of recovery from injury, the person may revert back to familiar swimming stroke patterns that may exacerbate symptoms and prolong the recovery period.

The recommendation, therefore, is that when initiating aquatic exercise following injury, participants remain under the supervision of a trained clinician or aquatic specialist until such time as they are pain free and able to continue independently with their routines, and when warranted, transition to land-based physical therapy (Prins & Cutner 1999; Thein & Brody 1998).

THE ADVANTAGES OF EXERCISING IN THE WATER

Two important physical properties of water, buoyancy and viscosity, are key elements in designing effective aquatic exercises.

The Force of Buoyancy and its Effect on Weight Bearing During Immersion: The advantage derived from buoyancy is direct; when a person enters the water there is an immediate reduction in the effects of gravity on the body. The buoyant force of water decreases the effective weight of an individual in proportion to the degree of immersion. The ability to control joint compression forces by varying degrees of immersion is of particular benefit in the treatment of persons who demonstrate intolerance to axial loading, particularly in the spine, hips, and lower extremities. By monitoring the depths at which functional movements such as walking and stepping are performed, the effect of gravity can be re-introduced which in turn promotes effective recovery through gradual strengthening (Cole et al. 2004; Prins & Cutner 1999).

Viscosity of Water and Muscle Strengthening: The viscosity of the water offers tangible resistance. Because of the "drag" forces created by the water, the degree of effort is determined by the cross-sectional area of the moving body or limb, coupled with the velocity of the movement.

Water can be seen as providing a “variable accommodating” resistance. The advantage of an accommodating resistance is that it matches the applied force or effort. In clinical terms, because the resistance of the water approximates the applied muscular forces, the probability of exceeding tissue tolerances is reduced and consequently, the likelihood of exacerbation of the injury is dramatically reduced. The term “variable” refers to being able to change the speed or velocity of the movement. Because most human motion is variable in nature, functional gains are more likely to occur when exercising in this manner (LeFort 1994; Prins et al. 2006; Rahmann et al. 2009).

CARDIO-RESPIRATORY FITNESS AND MUSCULAR ENDURANCE IN THE WATER: The loss of cardio-respiratory fitness can be significant during recovery from injury. Therefore, early resumption of exercise is now considered essential to the successful return to pre-injury activity. Aquatic therapy allows the injured person to begin exercising earlier. Aquatic running or jogging, when supported by a flotation device, offers additional benefits, most notably, the maintenance of rapid stride frequencies without the impact of landing, and coordinated movements between the arms and legs (Becker & Cole 1994; Prins et al. 2006).

Insufficient muscular endurance, rather than insufficient strength, is now seen as the primary factor present in an individual's inability to maintain the margins of safety of the spine, particularly when performing the "activities of daily living". Recent research shows that the ability to improve and maintain spinal stability following injury requires low intensity, continuous muscle activation (Cole, et al. 2004; McGill 2001). As noted above, aquatic exercise allows for sustained movements with less risk of overuse.

Social, Emotional, and Psychological Benefits of Aquatic Physical Therapy: Patient motivation and compliance with treatment are positive determinants for the success of any rehabilitation program. Because of the unique properties of water, aquatic physical therapy is an excellent rehabilitation choice, ensuring a high degree of compliance (Becker, Cole 1994).

CLINICAL DIAGNOSES AND CONDITIONS TREATED WITH AQUATIC EXERCISES.

Injuries to the Spine and Extremities: The therapeutic advantages of exercising in the water for early restoration of joint mobility in the spine, combined with progressive strengthening are well documented (Fappiano & Gangaway 2008; Lund et al. 2008; Rahmann et al. 2009). Exercises in water are used for strengthening the cervical and thoracic regions and are coupled with strengthening of the scapula stabilizers and glenohumeral musculature (Becker & Cole 1994; Cole et al. 2004; Prins & Cutner 1999).

For treatment of cervical injuries, an added advantage of the water is the ability to perform neck-strengthening exercises while floating in the prone position. When a mask and snorkel are used for breathing in the prone position, the buoyant force of the water can be relied on to support the weight of the head. This relieves injured muscles and associated soft tissue from the responsibility of counteracting anticipated gravitational forces.

Although the treatment of lower back injuries can take various forms, a common goal is to increase strength and mobility of the weakened area. Being supported by the water while standing or walking at varying depths, alters the axial loading on the spine. Gravitational forces are also minimized when the patient assumes a prone or supine floating position. Swimming and kicking in the prone and/or supine body positions, utilizing the neutral spine concept and modifying stroke mechanics for individual patients (Cole et al. 2004; Lund et al. 2008).

When recovering from hip, knee and ankle injury, especially after surgery, the force of buoyancy can be used to decrease the weight of the body while promoting early ambulation. Because joint reaction forces on the knee can reach several times body weight (Fappiano & Ganga-
TREATMENT OF ARTHRITIS, DIABETES, NEUROLOGICAL DEFICITS AND PERMANENT PHYSICAL DISABILITIES: Aquatic physical therapy is now also prescribed for persons diagnosed with arthritis and diabetes. The water reduces the pressure-induced loads on the joints and consequently allows continued exercising with less risk of internal injury. This is of particular importance because indiscriminate participation in physical activities may compromise the health of both Type 1 and Type 2 diabetics because these conditions are vulnerable to the stresses imposed by many types of activities (Becker & Cole 1994; Cole et al. 2004).

Exercising in the water is recommended for persons with neurological deficits which may have developed as a result of a Stroke (CVA), tumors of the C.N.S., and conditions associated with progressive skeletal muscle dysfunction such as Multiple Sclerosis. Because the density of water necessitates slower and more controlled movements, re-learning functional neuro-motor patterns is facilitated by the hydrostatic pressure which increases proprioceptive and kinesthetic awareness. Individuals are also less apprehensive about practicing these skills in the water because the risk of injury from loss of balance is eliminated (Becker & Cole 1994; Degano & Geigle 2009).

Aquatic exercise has been used extensively as a rehabilitative and therapeutic modality for individuals with permanent physical disabilities. The freedom of movement and the ability to exercise muscles which cannot overcome gravitational constraints make swimming and related aquatic activities invaluable for persons with a wide range of physically disabling conditions such as Amputation, Cerebral Palsy and Paraplegia (Becker & Cole 1994).

RESEARCH IN AQUATIC REHABILITATION
By combining active physical therapy in the water with ongoing research in the biomechanics of aquatic motion, a multi-disciplinary approach to rehabilitation can promote the design of new equipment and the efficacy of treatment protocols. Examples of research that focuses on aquatic physical therapy include monitoring kinematic and kinetic changes as they relate to increasing mobility and relative strength during aquatic physical therapy (Becker & Cole 1994; Prins et al. 2006; Prins & Cutner 1999).

REFERENCES
Training at Real and Simulated Altitude in Swimming: Too High Expectations?

Rodríguez, F.A.

Institut Nacional d’Educació Física de Catalunya, Universitat de Barcelona, Spain

Altitude/hypoxic training is a common practice among swimmers although scientific evidence is scarce and its benefits remain controversial. While acute hypoxia deteriorates swimming performance, chronic hypoxia may induce acclimatization effects which could improve aerobic capacity and therewith performance upon return to sea level. Other potential benefits such as improved exercise economy, enhanced muscle buffer capacity and pH regulation, and improved mitochondrial function have also been postulated. This paper aims to review current methods of altitude/hypoxic training and to discuss the available scientific evidence on the effects and potential benefits on sea-level swimming performance.

Key words: Altitude training, hypoxia, hypoxic training, intermittent hypoxia

INTRODUCTION

Altitude/hypoxic training (AT) plays an important role in preparing swimmers all over the world. Unfortunately, there is a remarkable lack of controlled studies on AT in swimming and the evidence supporting most approaches in athletes (Wilber, 2004), particularly in swimmers (Truijens & Rodríguez, 2010), remains inconclusive. Moreover, field observations and also research studies (Chapman et al., 1998) show that AT may work for some athletes and not for others.

It has been estimated that an Olympic swimmer should improve his or her performance by about 1% within the year leading up to the Olympics to stay in contention for a medal (Pyne et al., 2004). A recent meta-analysis concluded that the expectable performance benefit from AT for elite athletes can be as high as 1.6% (Bonetti & Hopkins, 2009). Perhaps a worthy strategy if a medal is just a tenth of a second away.

This paper aims to provide a brief, critical overview of peer-reviewed scientific literature on AT for the improvement of swimming performance at sea-level.

IS ALTITUDE/HYPOXIC TRAINING BETTER THAN TRAINING AT SEA LEVEL?

Table 1 presents a summary of AT studies from the international scientific literature, with swimmers. In view of this table, the answer to the question should likely be negative. However, the heterogeneity of research designs, testing methods, performance level of subjects and performance indicators make it difficult to derive sound conclusions based on the limited evidence available. Most of our knowledge derives from studies conducted in other sports such as long distance running, cycling, Nordic skiing and orienteering.

Table 1. A summary of studies of altitude/hypoxic training with swimmers

<table>
<thead>
<tr>
<th>Mode of hypoxia / Strategy</th>
<th>Level / Gender</th>
<th>Control / Design</th>
<th>n</th>
<th>VO₂max</th>
<th>Altitude</th>
<th>Duration</th>
<th>Effect on performance</th>
<th>Effect on VO₂peak</th>
<th>Other outcomes</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural altitude LHI-TH</td>
<td>College M</td>
<td>No pre-post</td>
<td>15</td>
<td>4.2 L/min</td>
<td>2300 m</td>
<td>2 wks</td>
<td>↑ at 200 and 500 yd TT</td>
<td></td>
<td></td>
<td>Fadhfar &amp; al. (1967)</td>
</tr>
<tr>
<td>Natural altitude LHI-TH</td>
<td>Elite junior M+F</td>
<td>No pre-post</td>
<td>16</td>
<td>2100-2300 m</td>
<td>3 wks</td>
<td></td>
<td>↑ Vmax and V₄ (+2.5%) at incremental 5x100 or 5x400 m test</td>
<td>↑ thb-mass (+3.5%)</td>
<td></td>
<td>Friedman &amp; al. (2005)</td>
</tr>
<tr>
<td>Natural altitude LHI-TH</td>
<td>Elite M</td>
<td>No pre-post, same group at two altitudes</td>
<td>9</td>
<td>59</td>
<td>1850 vs 1200 m</td>
<td>13 d</td>
<td></td>
<td>↑ Vmax at 200 m TT (+8.5%)</td>
<td>↑ Vmax at 2000 m TT (+7.5%) and at 400-m TT (+4.5%) after 1-wk taper</td>
<td>↑ in [H], Htc, thb-mass not measured</td>
</tr>
<tr>
<td>BHE hypobaric Hi-Lo</td>
<td>Elite and subelite M+F</td>
<td>Pre-post, matched-paired</td>
<td>8/8</td>
<td>59</td>
<td>Rest at +4000-5500 m</td>
<td>3 h/d over 2 wks</td>
<td>↑ Vmax at 200 m TT (+8.5%)</td>
<td>↑ VO₂peak at 200-m TT (+7.5%) and at 400-m TT (+7.5%) after 1-wk taper</td>
<td>↑ thb-mass (+4.5%*)</td>
<td>↑ Vmax at 2000 m TT (+7.5%) after 1-2 d, not after 15 d</td>
</tr>
<tr>
<td>BHE hypobaric Hi-Lo</td>
<td>Elite M+F</td>
<td>Pre-post, two groups living at 1200 m</td>
<td>9/9</td>
<td>58</td>
<td>at 1200 m</td>
<td>13 d; 16 h/d</td>
<td>↑ Vmax at 5x200 m and 2000 m TT conducted at 1200 m Only controls improved</td>
<td>↑ n.s. (+4.5% in H group)</td>
<td>Both groups equally improved</td>
<td>↑ in [H], Htc, thb-mass not measured</td>
</tr>
<tr>
<td>BHE hypobaric Hi-Lo</td>
<td>Trained M+F</td>
<td>Matched-paired, randomized, double blind</td>
<td>6/7</td>
<td>55</td>
<td>Rest at +4000-5500 m</td>
<td>3 h/d, 5-d/wk over 4 wks</td>
<td>↑ Vmax at 100 &amp; 400 m and incremental swimming flame test in both groups</td>
<td>↑ at incremental swimming flame test (+4.5%)</td>
<td>Both groups equally improved</td>
<td>↑ Ventilatory threshold (&lt;12.5%)</td>
</tr>
<tr>
<td>BHE hypobaric Lo-Hi</td>
<td>Trained M+F</td>
<td>Matched-paired, randomized, double blind</td>
<td>8/8</td>
<td>48-50</td>
<td>Training at +2500 m</td>
<td>12.5 min of high intensity bouts added, 3 x/wk over 5 wks</td>
<td>↑ at 100 and 400 m TT Both groups equally improved</td>
<td>↑ at 100 and 400 m TT Both groups equally improved</td>
<td>↑ MAOD in both groups</td>
<td>+ MAOD in both groups</td>
</tr>
<tr>
<td>BHE hypobaric Lo-Hi</td>
<td>Trained M</td>
<td>Matched-paired, randomized</td>
<td>6/6</td>
<td>56</td>
<td>Training at +1600-2400 m</td>
<td>2 daily HT sessions, 5-d/wk over 3 wks</td>
<td>↑ at 100 and 200 m TT Both groups equally improved</td>
<td>↑ at 100 and 200 m TT Both groups equally improved</td>
<td>↑ MAOD in both groups</td>
<td>+ MAOD in both groups</td>
</tr>
</tbody>
</table>

LHI-TH: Living high-training high; LHI-LI: Living high-training low; BHE: Intermittent hypoxic exposure at rest and/or sleep; IHT: Intermittent hypoxic training; M/F: male/female; TT: Time trial; MAOD: Maximal accumulated oxygen deficit; TH: hypoxia/altitude group; N: normoxia group; VO₂max: maximal speed; V₄: speed at 4 mmol/L lactate. *Significantly different from values measured before altitude/hypoxic training or compared to control group (p<0.05); n.s.: non-significant difference (p>0.05).
CLASSICAL ALTITUDE TRAINING
Classically, AT has consisted of living and training at natural (terrestrial) altitude, i.e. “living high-training high” (LH-TH). The prevailing paradigm which supports this practice is that LH-TH (about 2,000-3,000 m) is linked to an accelerated production of erythrocytes, which leads to an increase in VO2max, ultimately improving endurance performance.

Surprisingly though, there are no reports in the available scientific literature of controlled studies with swimmers. Even if designs without a sea level control group are very questionable and are considered not suitable for training research, it is of note that three uncontrolled studies have tested LH-TH in swimmers. Two of them failed to prove positive effects neither on 100- nor 500 yd swimming performance nor on VO2max (Faulkner et al., 1967; Roels et al., 2006). In fact, the latter showed a small improvement when subjects lived and trained during 13 days at 1200 m but not at 1850 m. The third study with junior swimmers is rather puzzling, since it showed an improvement on maximal speed and at 1200 m but not at 1850 m. The third study with junior swimmers is rather puzzling, since it showed an improvement on maximal speed and at 1200 m but not at 1850 m.

A more recent approach, first developed by Levine and Stray-Gundersen and known as “living high-training low” (LH-TL), has been shown to improve sea level performance in runners of various levels. In essence, LH-TL allows robust altitude acclimatization, while simultaneously allowing athletes to “train low” for the purpose of replicating sea-level training intensity and oxygen flux (Levine & Stray-Gundersen, 1997; Stray-Gundersen et al., 1999). However, LH-TH, proven useful with long distance runners and orienteerers (Wehrlin et al., 2006) in events lasting 8-20 minutes, has never been tested in swimming, in which most events are below 5 min.

Hence, based on available scientific literature, training at natural altitude has failed so far to prove useful for the enhancement of sea level performance in swimmers (Wilber, 2004; Truijens & Rodríguez, 2010). This fact is particularly remarkable bearing in mind that swimming coaches from many countries include AT in their planning and swimmers are among the most frequent users of high altitude training facilities.

INTERMITTENT HYPoxic TRAINING (IHT)
Since most events in swimming require large activation of the anaerobic metabolism (Rodríguez & Mader, 2010), the enhancing effects of IHT on anaerobic metabolism or buffer capacity have lead swimming scientists to test the hypothesis that this method could improve swimming performance more than equivalent training at sea level.

Two studies have been conducted with swimmers (table 1). In a first study (Truijens et al., 2003), sixteen well-trained collegiate and master swimmers were matched for gender, performance level and training history and assigned to either IHT or control groups in a randomized, double blind, placebo controlled design. All subjects completed a five week training program, consisting of three high intensity training sessions weekly in a swimming flume breathing hypoxic (=2,500 m) or normoxic air, and supplemental low to moderate intensity sessions in a pool. Although both groups improved performance in 100- and 400-m time trials and VO2max, no differences between groups could be demonstrated. Moreover, neither swimming economy nor anaerobic capacity improved with this training. In a second matched-paired, controlled study using a similar training regimen, Ogiña and Tabata (2003) found a 10% increase in anaerobic capacity as measured by the maximal accumulated oxygen deficit (MAOD) after two weeks of hypoxic training in nine competitive male swimmers. However, both groups equally improved VO2max, and swimming performance in 100 and 200-m time trials, thus it was not possible to establish an additional benefit.

INTERMITTENT HYPOXIA EXPOSURE (IHE)
Another strategy is IHE at rest or during sleep in hypobaric or normobaric environments (nitrogen houses, hypoxic tents/rooms) or using hypoxic breathing apparatuses combined with sea-level training. This should theoretically induce physiological adaptations without hampering training workload, thus allowing a comparison with LH-TL.

Two IHE studies have been conducted with swimmers using hypobaric chambers (table 1). In a first study (Rodríguez et al., 2003), sixteen elite and sub-elite swimmers were assigned to one of two groups in a matched-paired, randomized design, and half of them combined sea-level training with IHE over 2 weeks (3 h/d) at a simulated altitude of 4,000-5,500 m and were compared to the control group. Although all swimmers followed identical training plans, the IHE group significantly improved swimming performance in a 200-m time trial (-1.3 s, 0.9%), associated with an increase in peak VO2 both at 200-m (+9.3%) and 400-m (+5.4%) time trials.

In a second, match-paired, randomized, double blind, placebo controlled study (Rodríguez et al., 2007), 4 weeks of 4,000-5,500 m IHE was administered to 13 swimmers and 10 runners distributed in two groups (IHE and controls). Swimmers performed duplicated 100 and 400 m time trials, and VO2max tests in a swimming flume within three weeks before, and during the first and third week after the intervention. When swimmers were considered separately, the IHE group, but not controls, showed a significant increase in VO2 at the ventilatory threshold (VT; +8.9) and in maximal minute ventilation (+10.6%) immediately after the intervention, as well as a significant increase in VO2max relative to body mass (+7.5%) and VO2 at VT (+12.1%) two weeks after, following a pre-competition taper. Intriguingly, these changes could not be attributed to increased red blood cell or haemoglobin mass (Gore et al., 2006), sub-maximal swimming economy (Truijens et al., 2008), nor to hypoxic and hypercapnic ventilatory control changes (Townsend et al., 2004). The hypothesis was raised that these changes could have been the combined effect of IHE and tapering, thus suggesting that this approach might be useful immediately before competition.

In another controlled study using normobaric hypoxia, a group of swimmers spent 13 days living and training at 1200 m, while another group (IHE) was exposed to 16 h per day to simulated altitude at 2,500 m (5 days) and 3,000 m (8 more days) in hypoxic rooms. Despite an increase in total haemoglobin in the IHE group (+8.5%), no improvement was observed in VO2max or maximal speed at 4x200-m and 2,000-m maximal tests (Robach et al., 2006). Interestingly, swimmers in the control group (LH-TH at 1,200 m) did improve performance in both tests immediately after, but not 15 days after the intervention, again without any significant change in haemoglobin mass.

In terms of haematological response, it is of note that a recent analysis of 15 LH-TH studies conducted at real and simulated altitude has indicated that moderate altitude/hypoxic exposure of more than 12 h per day is likely to increase total haemoglobin mass by about 1% per 100 hours of exposure (Gore et al., 2008). This would imply a minimal duration of 21 days to attain about a 5% increase in haemoglobin.

Hence, despite the large amount of research performed in the last decade and some promising results, swimming performance enhancement by means of IHE is still controversial, both in terms of performance benefits and mechanisms involved, which do not seem to be related to haematological acclimatization effects.

CONCLUSIONS
Based on available scientific literature, there is no evidence that training at natural altitude enhances swimming performance more than training at sea level. Based on research conducted in other sports, AT would require at least 3 to 4 weeks at 2,100 to 2,500 m of altitude to elicit a robust acclimatization response (primarily red cell mass increase) in the majority of athletes. The optimal approach is likely to be LH-TL, in which one “lives high” (i.e., 2,100-2,500 m) to get the benefits of altitude acclimatization and “trains low” (1,250 m or less) to avoid the detrimental effects of hypoxic exercise. In fact, training at hypoxia (as in LH-TH or IHT) does not appear to provide any physiologic advantage over normoxic exercise and might even impair performance. Whether the
performance benefits would be similar for swimmers compared to other endurance trained athletes is not known and requires further research.

Swimming performance enhancement by means of IHF is still controversial. However, it is likely that at least 12 h/day at 2,100–3,000 m for 3 to 4 weeks may suffice to achieve a significant increase of red cell mass. Shorter exposure to more severe hypoxia (e.g., 4,000 to 5,500 m, 3 h/day for 2 to 4 weeks) combined with sea-level training may enhance VO_{2max}, ventilatory threshold and middle-distance swimming performance after pre-competition tapering, although the mechanisms are unclear.

In any case, there is substantial individual variability in the outcome of every AT strategy. Since none of these approaches has conclusively proven to enhance swimming performance, more research is warranted to clarify their effects and mechanisms.

THE ALTITUDE PROJECT
To clarify these effects and mechanisms in swimmers, a group of researchers from universities and sports organizations of different nations have developed a major collaborative international swimming study called The Altitude Project starting in October 2010 (Rodríguez & Levine, 2010). The project is open to sports and scientific organizations from all countries willing to contribute with recruiting and funding athletes, coaches and scientists. Information is available from: thealtitudeproject@gmail.com.

REFERENCES
Muscle Fatigue in Swimming

Rouard, A.H.

Laboratoire de Physiologie de l’Exercice, Université de Savoie, France

Fatigue is a complex process which could be related to different alterations either of the central nervous system and/or of the muscles. Few studies have focused on the biomechanical evaluation of fatigue in swimming. EMG results indicated either an increase of integrated EMG (IEMG) for muscles with sub-maximal activation or a decrease of IEMG for muscles strongly involved. Moreover, the frequency contents shift toward lower frequencies either for Maximal Voluntary Contraction (MVC) realised before and after an exhaustive test or during a maximal swimming test. Changes in muscular activation were associated with a decrease of force production (dry land strength or tethered or semi-tethered or swimming hand forces) and to changes in the path of the hand. Fatigue appears to be related to the task, the subject and the muscle.

Keywords: front crawl, fatigue, electromyography, forces, kinematics.

INTRODUCTION

The swimmers performance is determined by the ability to generate propulsive forces while reducing the resistance to forward motion. Propulsive forces are mainly generated by 3D limb movements in response to unstable loads created by the water. As in all human activities, fatigue could be defined as an acute impairment of performance. In regard to the movement generation process, fatigue could be related to central and/or peripheral alterations. The central component of fatigue could be due to the decrease of the CNS activation (nervous order and/or motor neuron activation). The peripheral fatigue is related to an alteration of the neuromuscular junction and/or the deficit of substrates, blood flow, and/or dysfunction of the sarcomer. Consequently, fatigue is a very complex phenomenon, which could be evaluated through different approaches (physiology, Electromyography (EMG) and Mechanics).

Because of the complexity of the movement in an aquatic environment, few biomechanical studies have focused on fatigue in swimming. EMG has largely been used in the evaluation of fatigue during sustained isometric contractions. Many authors have observed a shift to lower frequencies of the EMG signal spectrum. In the 90’s, a novel approach (time-frequency treatment) was proposed for calculating spectral parameters from the surface myo-electric signal during cyclic dynamic contractions for which changes in muscle length, force and electrode position contributed to the non-stationary status of the signal (Knafflz and Bonato, 1999). Recently this approach was applied to swimming movement (Caty et al, 2007).

The present review concerns the effect of fatigue on muscular activation and the associated changes in forces and hand trajectories.

METHODS

Most of the studies on fatigue in swimming have been conducted on male international swimmers. Different maximal tests were performed by the subjects depending on the authors (i.e. maximal 400m swim in a flume for Monteil et al, 1996, or maximal 4*50m for Caty et al, 2007).

During the test, EMG was synchronised with video acquisition. For EMG, the authors used either surface electrodes (Wakayoshi et al, 1994, Rouard et al, 1997, Caty et al, 2007) or fine wire electrodes (Monteil et al, 1996). Shoulder and upper limb muscles were those most investigated. All the authors applied the same guidelines for the location of the electrodes (belly of the muscle) and the skin preparation (Clarys and Cabri, 1993). Signals were stored on a memory card or on the soundtrack of the video camera. For the amplitude treatment, the raw EMG signals were rectified, smoothed and then integrated (IEMG). For each subject, and each muscle, the IEMG were normalised according to the maximal dynamic value observed during the testing procedures. For the frequency treatment, Aujouannet et al (2006) applied a Fourier transformation to evaluate the frequency contents of static Maximal Voluntary Contractions (MVC) performed just before and after the exhaustive swimming test (4*50m). For the swimming signals, Caty et al (2007) extracted, with a statistical detector, the activation interval corresponding to each stroke and each muscle. For each detected muscle burst, the Choi-Williams transformation was then computed. These particular transformations had already proven effective in the analysis of strongly non-stationary EMG signals recorded during dynamic exercise (Knafflz and Bonato, 1999). The instantaneous mean frequency of the signal burst (MNF, Hz) was calculated for each stroke cycle.

For the kinematic evaluation of fatigue, at least 2 underwater cameras were used to analyse the 3D movements of the upper limbs. The video was digitised frame by frame to get the hand trajectories and/or the hand velocity and/or different angles (sweep back and attack hand angles, limbs angles).

During the MVC, the forces were recorded using a strain gauge, while during swimming the authors used either direct force measurements such as a tethered or semi-tethered apparatus (Aujouannet et al, 2006, Rouard et al, 2006) or an indirect approach calculating the lift, drag and resultant hand forces according to Schleihaufl’s method (Monteil et al, 1996)

RESULTS

Results indicated a decrease of IEMG for the most activated muscles (M. Deltoideus or M. Flexor carpi) (Wakayoshi et al, 1994; Caty et al, 2007) (Figure 1) or an increase of IEMG for muscles with sub-maximal contractions depending on the phase of the stroke (M internal or external rotators) (Monteil, 1996) (Figure 2).

Figure 1: Mean (SD) of the normalised IEMG of the muscles Flexor (FCU) and Extensor (ECU) carpi ulnaris for the 1st and the 4th of the maximal 4* 50m test (adapted from Caty et al, 2007)

Figure 2: Normalised IEMG of the shoulder muscles at the beginning (fresh) and end (fatigue) of a maximal 400m test swim in a flume (adapted from Monteil et al, 1996).

A shift of spectral parameters of the EMG’s of the M. biceps and triceps brachii toward lower frequency was observed during maximal voluntary contractions (MVC) realised before and after a maximal 4*50m swimming test (Aujouannet et al, 2006). During the 4*50 maximal test a de-
The derivative of the instantaneous mean frequency (MNF) was noted for the M. antagonist Flexor and Extensor carpi (Caty et al, 2007) (Figure 3).

Figure 3: Mean (SD) of the percentage of decrease (PD%) of the Instantaneous Mean Frequency (MNF) between the 1st 25m and the last 25m of the maximal 4*50m test (adapted from Caty et al, 2007). These changes were associated with a decrease in force production either for the maximal dry land strength or for maximal tethered force or for maximal power (Rouard et al, 2006) (Figure 4).

Figure 4: Means (SD) of Isometric (Fiso), full tethered (Fpmax), ½ tethered (Fp) forces and power (P) before and after a maximal 4*50m test (Rouard et al, 2006).

Concerning the hand forces, both the Resultant and Efficient components decreased during the insweep phase and increased during the out-sweep in a state of fatigue indicating a shift of the force production from the in-sweep to the out-sweep at the end of the maximal 400m front crawl test, swum in a flume (Monteil et al, 1996) (figure 5).

Figure 5: Resultant and Efficient component forces at the beginning and at the end of a 400m test swum in a flume (N=9) (adapted from Monteil, 1996).

Kinematic data corroborated the EMG and kinetics results. In a fatigue state, the spatial hand path remained unchanged with a greater duration of the catch, insweep and out-sweep phases (Aujouannet et al, 2006) (figure 6).

Figure 6: Spatial (A) and temporal (B) values of the hand path for the 1st 50 (white bar) and the 4th 50 m (grey bar) of the maximal 4*50m test: F (maximal forward coordinate), B (maximal backward), Ex (exit from the water), D (maximal depth), O (maximal outward) and I (maximal inward) * significant difference between the 1st and 4th 50 m at p<0.05.) (Aujouannet et al, 2006).

Monteil et al (1996) observed similar results after a maximal 400m test swum in a flume with a decrease of hand velocity during the insweep phase (Figure 7).

Figure 7: Hand velocity during the different phases of the stroke, at the beginning and at the end of a maximal 400m freestyle test conducted in a flume (N=9) (adapted from Monteil, 1996).

**DISCUSSION**

The increase of the IEMG for some muscles in a state of fatigue (e.g. internal rotators) reflected the recruitment of additional motor units to maintain the swim task. Contrarily, the decrease of IEMG of other muscles (i.e. FCU) reflected a strong fatigue state corresponding to a high involvement of these muscles in the swim task. Moreover, the shift...
of the EMG to lower frequency in the fatigue condition either for the MVC or during the swim test indicated a preferential recruitment of slow motor units and/or a decrease of velocity conduction. Large individual differences were observed reflecting the variability in muscle fibre and/or motor unit recruitment and/or subject capacity restoration.

The muscular fatigue contributed to the decrease of force production either for the dry land or swimming forces, especially during the in-sweep phase.

The kinematic and kinetic results suggested that in fatigue conditions swimmers increased the first gliding phase and limited the force production during the in-sweep (i.e. the most mechanically constrained phase) to favor the final up-sweep phase.

CONCLUSION
Muscular fatigability is specific to the muscle, the exercise and the subject. The muscular changes contributed to the loss of force and to a decrease of hand velocity. Biomechanical methods allowed the resolving of individual strategies of swimming and adjustments caused by fatigue. In this way, biomechanical evaluation could be a useful tool to individualize the training process of top level swimmers, especially regarding coping with fatigue.

Future investigations will be required to evaluate the load-sharing across muscles and/or to determine the central and peripheral components of fatigue in swimming.

REFERENCES


Inter-Limb Coordination in Swimming
Seifert, L.
Centre d’Etude des Transformations des Activités Physiques et Sportives (CETAPS), University of Rouen, Faculty of Sports Sciences, France

Expert and non-expert swimmers show both similarities and differences in their inter-limb coordination, which should be of interest to scientists and coaches. The effects of speed, active drag, energy cost and breathing have been analysed during incremental tests and racing, particularly in front crawl. In the past, it was reported that inter-limb coordination should show an opposition mode, i.e. continuity between the propulsion of the two limbs, in order to minimize the intra-cyclic speed variations. However, the inter-limb coordination mode adopted by swimmers emerges from the three types of constraints defined by Newell (1986): organicism, task and environmental. The swimmer’s skill level, specialty, gender, anthropometry, handedness and breathing laterality act as organicistic constraints; the imposed race pace, stroke frequency, breathing frequency and pattern can be considered as task constraints; and active drag and its correspondent speed are the environmental constraints. Inter-limb coordination was found to vary from catch-up or glide mode to superposition mode, indicating that the opposition mode is only the best ‘theoretically’ and that the glide mode is not a technical mistake. Therefore, rather than focusing on developing an ideal coordination mode, coaches would do better to vary the learning situations for swimmers as they seek to develop optimal coordination. This paper presents new information about inter-limb coordination based on the relative duration of arm stroke phases and the time gap between propulsive actions assessed by the index of coordination (IdC) in front crawl. Interesting findings have emerged with implications for how both expert and non-expert swimmers should be coached.

Key words: motor control, biomechanics, coordination mode, constraint.

INTRODUCTION
Why is it important to talk about inter-limb coordination in swimming? The forward displacement during swimming results from the ratio between propulsive and resistive forces, and many studies have thus quite rightly focused on active drag minimization, propulsion generation and/or propulsive efficiency (Toussaint & Truijens, 2005). However, two swimmers can apply the same force and/or deliver the same power output without exhibiting the same inter-limb coordination. In fact, the swimmer has to organize the transition between the underwater and above-water phases of the cycle (except in breaststroke), and the time devoted to propulsion and glide during the underwater part of the cycle.

Thus, inter-limb coordination may not automatically serve only to propel the body forward, as part of the motor organization may be dedicated to floating and breathing. Inter-limb coordination is related to motor control and motor learning, which raises the question: Is there a direct link between coordination and propulsion? The key point defining the beginning of propulsion is subject to debate, as Newton’s third law dictates a backward hand movement, while the Bernoulli hydrodynamics law favours a hand sculling movement. Our studies of inter-limb coordination thus deliberately used key points that were qualitatively easy to observe. These may have overestimated the boundaries of propulsion (beginning and end) but nevertheless provided a useful tool for analysing propulsive behaviour. For example, in front crawl, Chollet et al. (2000) assumed that arm propulsion starts when the hand moves backward. This means that relative hand speed calculated by subtracting absolute hip speed from the absolute hand speed observed on 2D is used to determine the backward hand speed (i.e. in the swimmer’s reference and not in the pool reference). Then, from the key points determining the beginning
and the end of the arm stroke phases in front crawl (entry-catch, pull, push, recovery), Chollet et al. (2000) established an index of coordination (IdC) that quantifies the time lag between the propulsion of one arm and that of the second arm. The IdC has been adapted for the four strokes (backstroke, Chollet et al., 2008; butterfly, Chollet et al., 2006; breaststroke, Chollet et al., 2004; for a review, Chollet & Seifert, 2010, Seifert & Chollet, 2008) in order to assess the time gaps quantifying the upper limb coordination in the alternating strokes and the upper-lower limb coordination in the simultaneous strokes. Therefore, when IdC = 0%, the mode is opposition; when IdC < 0%, the mode is catch-up; and when IdC > 0%, the mode is superposition. From a functional point of view, it is nevertheless reasonable to consider the opposition mode as -1% < IdC < 1%. It should also be noted that these indicators remain indices of coordination and not propulsion. Coordination can be studied from an 'egocentric' point of view (degrees of freedom, i.e. limb movement possibilities like flexion and extension, pronation and supination, rotation, etc.) rather than from an 'allocentric' point of view (propulsion phases and concepts). Seifert et al. (2010a) therefore recently assessed upper-lower coordination in breaststroke from the angle and angular velocity of the elbow and knee to determine their coupling by the calculation of the continuous relative phase.

Two swimmers can achieve the same performance (swimming speed) using different modes of inter-limb coordination. Thus, a second question arises: Is there a relationship between coordination and performance? In other words, is there an ideal inter-limb coordination mode? Should the coach advise the swimmer to favour superposition coordination rather than opposition? Is the catch-up or glide mode a technical mistake? Should the beginner imitate the expert swimmer? Or is it reasonable to allow a temporary 'non-expert' coordination mode at the beginning of the learning and training process? The aim of this paper is to show that coordination emerges principally from interacting constraints (Newell, 1986): environmental (aquatic resistances and speed as resistance equal to speed squared), task (imposed by the operator, e.g., swimming at maximal intensity, swimming in fatigue condition) and organismic (corresponding to the swimmer’s characteristics, i.e. anthropometry, morphology, strength, etc.). From this perspective, the swimmer’s inter-limb coordination is a consequence of interacting constraints and not a cause (for a review, see Davids et al., 2008). Thus, coaches should (i) take the organismic constraints into account, (ii) find means to minimize the environmental constraints, and (iii) manipulate the task constraints to destabilize inadequate coordination in order to bring about a coordination mode not expected from the beginner’s initial behaviour. Direct manipulation of coordination to improve performance requires great care, however, and the swimmer should initially work at adopting the imposed behaviour without trying to improve performance. For example, if superposition coordination is the target coordination, the swimmer may increase his stroke frequency, thereby slipping through the water without achieving the expected performance. When coaches directly manipulate coordination, they therefore need to keep in mind the importance of maintaining the same performance level.

The following sections present the similar behaviours and main differences between expert and non-expert front crawl swimmers regarding (i) the effects of swim speed, active drag and energy cost; (ii) the relationships between coordination, propulsion and efficiency; (iii) the relationships between coordination and performance, bearing in mind that coordination may be either flexible or stable; and (iv) the effect of breathing, which suggests that swimmers organise their limb coupling not only to propel but also to breathe and float.

**COORDINATION, SWIM SPEED, ACTIVE DRAG AND ENERGY COST**

According to Newton's second law ($\sum \mathbf{F} = ma$, where $\mathbf{F}$ is the force, $m$ the mass and $a$ the acceleration), forward body displacement is related to the differences between the propulsive forces generated by the swimmer and the aquatic resistive forces (i.e. the environmental constraints).

In fact, forward body displacement seems to be a more complex process and the swimmer may cross several solutions, probably the production of propulsive forces, the minimization of active drag, the maximization of propulsive efficiency (i.e. minimization of kinetic energy) and the monitoring of inter-limb coordination.

Thus, when active drag and speed (active drag changes with speed squared) increase, inter-limb coordination is affected, particularly by a decrease in the time lag between two propulsions, which means that the relative duration of the glide and catch phases decreases. In front crawl, Chollet et al. (2000) and Seifert et al. (2004, 2007b) showed that speed increases lead to similar motor behaviour in expert male, expert female, and non-expert male swimmers: they increase the IdC and simultaneously increase stroke rate and decrease stroke length. Seifert et al. (2010b) used an arms-only protocol both on the Measuring Active Drag (MAD) system to assess active drag during an incremental test and while swimming in free condition to assess inter-arm coordination in front crawl. They showed a linear regression between active drag and IdC (0.64 < $R^2$ < 0.98), confirming that swimmers have to modify their motor organization when the task (speed) and environmental (drag) constraints increase.

Similar results were found when energy cost increased: reaching higher speed leads to higher energy expenditure and increases IdC and stroke rate (Morais et al., 2008; Seifert et al., 2009).

**COORDINATION, PROPULSION AND EFFICIENCY**

Only expert swimmers attain high speeds, as they are able to generate high power output and reach high IdC. Indeed, when expert swimmers increase their speed and/or their stroke rate above a critical value (respectively ~1.8 m.s$^{-1}$ and 50 stroke.min$^{-1}$), only the superposition mode is observed (Pordevin et al., 2006; Seifert et al., 2007b), which may be attributed to the dominance of wave drag. When moving at high speed in whole stroke (> 1.5-1.7 m.s$^{-1}$), wave drag becomes even greater, accounting for up to 50-60% of total drag (Toussaint & Trujils, 2005; Vennell et al., 2006). Using a process similar to the calculation of “hull speed” for a ship, the authors mentioned above found that the hull speed for a swimmer with an arbitrary height of 2 m was 1.77 m.s$^{-1}$ (Toussaint & Trujils, 2005). This finding coincides with the large increase in active drag found above this critical speed (>1.7-1.8 m.s$^{-1}$), as determined by the wave drag, the environmental constraints eliciting a superposition coordination of the arms. Indeed, it was recently shown that an increase in speed leads to simultaneous changes in drag force, power output and inter-arm coordination. While swimming only with arms in the free swimming condition, expert front crawl swimmers switch the inter-arm coordination from catch-up mode (IdC < 0%) to superposition mode (IdC > 0%) above a speed of 1.5-1.6 m.s$^{-1}$ at maximal intensity (Seifert et al., 2010c). Using arms-only on the MAD system, the same swimmers exhibited a drag force of 100-110 N at maximal intensity, developing a mechanical power output of ~200 W (Seifert et al., 2010c). Conversely, less-expert swimmers also swimming at maximal speed exhibited a drag force < 100 N, power output < 180 W and inter-arm coordination in catch-up mode (IdC < -6%), which did not enable them to reach the same speeds as the expert swimmers. On the other hand, a high IdC does not guarantee high speed, as the swimmer can slip through the water and/or spend a long time in the propulsive phase because of slowed hand speed, meaning low propulsive efficiency. Notably, Seifert et al. (2010b) showed that IdC increases with active drag in experts, but that at maximal intensity (swimming 25m all out) IdC is not correlated with propulsive efficiency for this sample of swimmers.

Moreover, when speed increased, expert swimmers increased IdC while their hip intra-cyclic speed variation remained stable with a coefficient of variation close to 0.15 (Schnitzler et al., 2008; Seifert et al., 2010c). Conversely, non-expert swimmers did not significantly change their arm coordination (which remained in catch-up mode) while their hip intra-cyclic speed variation increased (from 0.16 to 0.21). These results suggest that, unlike non-experts, expert swimmers make effective motor control adaptations.
adaptations to increased aquatic resistance. They also indicate that IdC is an interesting tool to assess motor control and motor learning, even though the links between coordination and propulsion and efficiency are not automatic. Therefore, if the coach's goal is to relate coordination to performance, the effectiveness of inter-arm coordination (i.e., IdC value) should be analyzed with regard to some of the indicators of propulsive efficiency (power output, intra-cyclic speed variations, swim speed/hand speed ratio, stroke index, power output/total power ratio).

COORDINATION AND PERFORMANCE: FLEXIBILITY-STABILITY?
As noted, the IdC value does not remain the same whatever the speed. Indeed, swimming speed is not uniform as the application of propulsive forces in water leads to acceleration and deceleration within the cycle, i.e., to intra-cyclic speed variations of the centre of gravity (Miller, 1975; Miyashita, 1971). The opposition mode of coordination thus appears as ‘theoretically’ ideal because it should allow propulsive continuity (assumed by the alternating actions of the two arms) and limit the intra-cyclic speed variations of the centre of gravity. In practice, there is not an ideal mode of coordination as inter-arm coordination changes with the task and environmental constraints. Moreover, an analysis of expert front crawl sprinters swimming from their slowest to their fastest speeds showed inter-individual variations in the range of inter-arm coordination modes and in speeds (Fig. 1). This raises the question: Is the expert swimmer an ultra-specialist in one stroke and one race distance or a swimmer with flexible behavior, able to win in several strokes and events (like L. Manaudou and M. Phelps)?

The first profile corresponds to swimmers with little ‘motor flexibility’ in coordination and speed. These could be ‘ultra-specialists’, training mostly in one way. For example, because they train mostly for endurance, triathletes maintain their inter-arm coordination in catch-up mode with extremely negative values for IdC (Hue et al., 2003). The second profile corresponds to an ineffective high value for coordination, because high speed cannot be attained. As pointed out by Seifert et al. (2007a), some non-expert swimmers switch to superposition coordination mode because they spend more time with their hand in the propulsive phase, due to slow hand speed, but therefore do not generate high force. The third profile corresponds to swimmers with stable inter-arm coordination while reaching high speeds. These swimmers may be focused on the change in the ratio between stroke rate and stroke length. For example, Figure 3 shows one swimmer of the French team (participated in the 4 x 100m at the Atlanta Olympic Games in 1996) who kept his coordination stable with IdC close to the ‘theoretically’ more efficient coordination mode (i.e., opposition), mostly changing his stroke rate/stroke length ratio.

The fourth profile demonstrates that, the longer the coordination curve, the greater the swimmer’s range of coordination, indicating motor flexibility in coordination. Indeed, the higher the maximal coordination and the lower the minimal coordination of the curve, the more the swimmer is exploring human potential. To the coach, this indicates that the swimmer attains a range of speeds depending on the type of coordination mode: catch-up mode by using glide time, or superposition mode by overlapping the propulsive phases. From this perspective, the IdC value itself does not indicate the swimmer’s performance, but only the behavioral flexibility with respect to the interacting constraints (Newell, 1986; Seifert et al., 2007b). As suggested above, coordination should be related to other parameters of propulsive efficiency in order to draw conclusions about performance.

On the other hand, race analyses have mostly pointed out that high performance is related to stability or minimal change in the stroking parameters, i.e., speed, stroke length and stroke rate (Sidney et al., 2010). Concerning arm coordination, expert swimmers showed relatively stable IdC values over the course of a race, whereas lower expertise and/or fatigue was indicated by an increase in IdC (Seifert et al., 2007a). For example, during a 100m race, Seifert et al. (2007a) observed that the non-expert swimmers (who seemed more tired as they took 8.5 s more than the experts to complete the 100m) increased IdC from opposition to superposition coordination in the last part of the 100m. According to Suito et al. (2008) and Toussaint et al. (2006), these changes in arm coordination may be related to lower hand speed, power output and propelling efficiency in the last part of the 100m (for the analyses of
the 200m event, see Alberty et al. (2005); for the 400m, see Schnitzler et al. (2010).

Last, as regards the task and environmental constraints, coordination flexibility or/and stability are useful indicators of motor skill in swimming.

WHY COORDINATION? TO GO FORWARD? OR ALSO FOR FLOATING AND BREATHING?
As suggested in the introduction, the limbs are coordinated not only to propel the body forward, but also to facilitate or improve floating and breathing. For example, expert and non-expert swimmers having unilateral breathing patterns (every 2 or 4 strokes) showed an asymmetric coordination, which was most often related to breathing laterality (i.e., a preferential breathing side) and motor laterality (arm dominance) (Seifert et al., 2005). This means that catch-up coordination mostly occurred to the same side as breathing and arm dominance, while the swimmer showed superposition coordination to the other side. This coordination asymmetry was found to be greater in non-expert swimmers because the time spent inhaling led them to a lag time in propulsion (Lerda et al., 2001). Notably, non-experts prolonged the catch with the arms extended forward to facilitate head rotation during breathing and thus by catch-up to the breathing side. Conversely, swimmers with bilateral breathing patterns (every 3 or 5 strokes) tended to balance the arm coordination by distributing the asymmetries (Seifert et al., 2005). Thus, it may be advisable to vary the learning situations to encourage symmetric coordination, i.e., alternating tasks with unilateral, bilateral, and frontal snorkel breathing. To confirm this hypothesis, breathing laterality was manipulated in non-expert swimmers by imposing seven breathing patterns, divided into unilateral patterns and bilateral patterns (Seifert et al., 2008). The authors showed that breathing to the preferential side led to an asymmetry, in contrast to the other breathing patterns, and the asymmetry was even greater when the swimmer breathed to his non-preferential side (Seifert et al., 2008). Moreover, coordination was symmetric in patterns with breathing that was bilateral, axed (as in breathing with a frontal snorkel) or removed (as in apnoea). From this viewpoint, arm coordination was not only determined by propulsion but also by breathing and motor laterality, suggesting that instructors should help swimmers (i) to determine their preferred side for unilateral breathing and (ii) to adapt the breathing pattern (e.g., by using bilateral patterns, apnoea in sprint, frontal snorkel) during training sessions when coordination asymmetry is disturbing the stroke too much.

CONCLUSION
The main contribution of inter-limb coordination analysis over the past decade has been the development of a useful tool for understanding motor skills in swimming. The main findings can be summarized as follows: (i) there is no "correct" coordination but only coordination in relationship to interacting constraints, (ii) appropriate coordination is not synonymous with good propulsion because a certain coordination mode is adopted to facilitate breathing or floating, and (iii) coordination is not the cause but mostly the consequence of these constraints, thus imposing a certain coordination mode does not guarantee high performance or efficiency. It is therefore advisable to analyse the organismic, task and environmental constraints leading to the current behaviour rather than considering an 'ideal' behaviour based on a 'theoretical' background.

ACKNOWLEDGMENT
I thank Didier Chollet, my principal colleague, who initiated the research about inter-limb coordination and supported me and many PhD students to work on this topic.

REFERENCES


Chapter 2. Biomechanics
Comparison of Manikin Carry Performance by Lifeguards and Lifesavers When Using Barefoot, Flexible and Fiber Fins

Abraldes, J.A.1, Soares, S.2, Lima, A.B.2,3, Fernandes, R.J.2, Vilas-Boas, J.P.1

1 University of Murcia, Faculty of Sports Sciences, Murcia, Spain
2 University of Porto, Faculty of Sport, Cifid, Porto, Portugal
3 Federal University of Ceará, Institute of Physical Education and Sports, Brazil

The use of fins is fundamental in aquatic sport and saving rescue activities, large variety of models existing in the market. The main purpose of this study was to compare two groups (lifeguards and lifesavers) performing a manikin carry effort using barefoot, flexible and fibre fins. Ten licensed lifeguards and ten lifesavers performed 3 x 25 m with barefoot, flexible and fibre fins in manikin carry connected to a cable speedometer that measured instantaneous velocity (v). For lifesavers, fibre fins allowed higher v values compared with flexible fins. No differences between fins models were observed regarding v of lifeguards. Additionally, the use of flexible or fibre fins do not show differences in fatigue index for both groups.

Key words: Biomechanics, lifesaving, rescue, fatigue

INTRODUCTION

The use of fins is fundamental in some professional and sport aquatic activities (e.g. diving, underwater fishing, sea rescuing, fin swimming, underwater hockey and sportive diving). Aquatic rescue considers both professional and sportive events, in which lifeguards and lifesavers are being involved, respectively. The purpose of each group is different: lifeguards are required to rescue a person for saving his/her life and don’t compete; lifesavers are asked to achieve a best performance against the stopwatch and don’t save real persons. Fins are a fundamental element for both lifeguards and lifeguards, besides lifesavers don’t use fin in every events. Besides the difference in purposes, to choose the best fin model is a common concern of lifesavers and lifeguards.

Fins can be classified in two major types: mono and single fins. Each type presents a large variety of models, being distinguished by their stiffness, surface (width and length), flexibility and composition. Although monofins allow higher velocities when compared to single fins (Zampano et al., 2006), they could not be used for lifesaving purposes, since they do not allow walking in a real rescue situation.

There are a limited number of studies on single fins efficacy. Nevertheless, some physiological parameters were studied by Daniel and Klauck (1992). Authors found that lactate accumulation and heart rate trends in life-saving are comparable to those produced by competitive swimmers. Economy and efficiency were assessed by Zampano et al. (2006), that found that large and heavy fins were characterized by approximately the same economy and efficiency of fins with smaller surface but better buoyancy. Carrying by chest or head techniques were characterized by Juntunen et al. (2006), and the velocity in aquatic rescue was assessed by Abraldes et al. (2007). Last ones showed that velocity was higher when fins were used, independently of the fin type.

Considering the large variety of fin models available, it is important to understand which is the best fin model fitting the needs of both lifesavers and lifeguards. Some studies were conducted in this topic, but in different populations, analysing swimming or mannequin-carry events using different effort distances (Abraldes et al., 2007), but lifeguards and lifesavers were never compared. Specialized literature leads to think that the best fin model is not necessarily the same for different populations but studies results are not homogeneous. In carry efforts related studies, results were different from those above. In fact, although differences were not found between different fin models in 25 m mannequin carry effort (Abraldes, 2004), in another study with a similar sample, Abraldes (2005) found best carry performances when stiff fins were used, comparatively with flexible, short and fibre fins. Additionally, for 50 m carry performed by university students, Abraldes (2006) found that the use of stiff fins allows higher performances comparatively with flexible fins, but only in the first 25 m of the effort. Contradictory findings could probably be related with differences in subjects’ number and characteristics.

Lastly, Abraldes et al. (2007) analyzed carry velocity with barefoot, flexible and fibre fins obtained by lifeguards. Authors observed that fibre fins can provide a steadier velocity during a short sprint, comparatively with flexible fins.

Since it was never tried to compare lifesavers and lifeguards concerning fin models, the main purpose of this study was to compare these two groups performing a manikin carry effort using barefoot, flexible and fibre fins. Complementarily, it was aimed to study fatigue in carry, since literature is scarce about this subject.

METHODS

Twenty subjects, 10 licensed lifeguards and 10 lifesavers, were tested. The main physical characteristics of the subjects are described in Table 1.

Table 1. Mean ± SD values of the subjects main physical characteristics.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>BMI (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifeguards (n=10)</td>
<td>17.08±2.24</td>
<td>72.90±11.71</td>
<td>176.43±3.96</td>
<td>23.37±3.33</td>
</tr>
<tr>
<td>Lifeguards (n=10)</td>
<td>27.44±10.79</td>
<td>76.22±11.92</td>
<td>179.33±7.45</td>
<td>23.56±2.14</td>
</tr>
</tbody>
</table>

All tests were performed in a short course (25 m) indoor swimming pool with a mean depth of 2 m. The protocol consisted of a 3 x 25 m maximal swim trials carrying a manikin (Swedish model), with a minimum recovery time of 30 min. The manikin was constructed with a closed PITET plastic type, had a total height of 1 m and was totally filled of water in order to have a total land weight of 80 kg. The trials’ order was randomized, performing with barefoot, with flexible fins (Gabbiano Francis, 45 cm length and 20 cm width, with a closed shoe part and a small opening for the toes fingers), and with fibre fins (Special Films, model Sebak Saber 140 Hard M, 65 cm length and 22 cm width, being rectangular on is tail, with a open shoe part on the heel and fixed to the lifeguard foot by a brace).

Each 25 m bout started within the water, with the subjects in contact with the wall or the starting block, head in emersion and carrying the mannequin (lateral-dorsal position). Subjects could kicking and use one arm for propulsion. A cable speedometer (Lima et al., 2006), was connected to the mannequin in order to obtain instantaneous velocity (v) during total event. The cable speedometer uses an incremental sensor with 500 points resolution per revolution. A brake engine allows the full system inertia to be insignificant, keeping the line always stretched. Accuracy and reliability of the speedometer was confirmed by Lima (2006). During the data analysis, the first two s the v curves of each swimmer were removed, minimizing the effect of the initial impulse, and focused the analysis on leg kicking only (there were no propulsive actions with the arms). The v were assessed over 2 s periods (Fig. 1), on three moments of the total v curve: (i) mean v correspondent to the initial 2-4 s of the total effort time; (ii) mean v correspondent to the middle part of total effort time and (iii) mean v correspondent to the last 2 s of total effort time. Total effort time was defined as the time duration between the first and the last v peak of the v(t) curve, after initial impulse has been removed.

42
The mean slopes corresponding to the individual regression lines plotted between initial and middle \(v\), between middle and final \(v\) and between initial and final \(v\) were calculated for both groups. The mean fatigue indexes (FI) corresponding to the first and second middle and to the total effort time were also assessed according to the following formula:

\[
F = \frac{(\bar{v}_f - \bar{v}_i)}{\bar{v}_i},
\]

where \(\bar{v}_i\) is the mean \(v\) computed during 2 s in the beginning of each part of the test (the total test distance or each middle part considered) and \(\bar{v}_f\) is the mean \(v\) computed during 2 s in the end of the respective distance. Formula 1 has already been used by Soares (2006). Mean \(v\), slope of the \(v(t)\) decline (\(v\) decay) and FI in the first and second middle parts of each 25 m, and in the total test, were used as fatigue criterions to study the fatigue induced during the total effort time, and during each middle parts, considering the three conditions tested.

The normality (Shapiro-Wilk test), sphericity (Mauchly Test) and homocedasticity of all distributions were confirmed. A paired simple T-test was used to compare \(v_{\text{mean}}\), slopes and FI corresponding to the first and second middle of the total effort time. T-Test was used for comparisons between lifesavers and lifeguards too. Tests were performed for each group. Repeated measures ANOVA have been applied to test differences between the three tested conditions. Significance was accepted at 0.05.

RESULTS

The \(v\) attained in the initial, middle and final moments of the 25 m carry effort can be observed in Table 2. Lifesavers performed faster than lifeguards in all three segments when using fibre fins. Carry velocity with flexible or fibre fins seemed to be indifferent for lifeguards. Lifesavers and lifeguards performed slower in the barefoot condition in any segment of the 25 m effort.

Table 2. Mean ± SD values of the velocity (m·s\(^{-1}\)) corresponding to initial, middle and final segments of the total carry effort performed with barefoot, flexible and fibre fins by lifesavers and lifeguards.

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>Middle</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifeguards</td>
<td>0.77±0.06</td>
<td>0.67±0.06</td>
<td>0.66±0.07</td>
</tr>
<tr>
<td>Lifesavers</td>
<td>1.12±0.13</td>
<td>1.03±0.10</td>
<td>0.99±0.10</td>
</tr>
<tr>
<td>Flexible fins</td>
<td>1.31±0.11*</td>
<td>1.09±0.12*</td>
<td>0.99±0.10*</td>
</tr>
<tr>
<td>Fibre fins</td>
<td>1.33±0.09*</td>
<td>1.21±0.11*</td>
<td>1.01±0.12*</td>
</tr>
</tbody>
</table>

Differences (p≤0.05) between groups: *different from lifeguards;
Differences (p≤0.05) between conditions: adifferent from barefoot; bdifferent from flexible fins;
Differences (p≤0.05) within conditions: *different from initial velocity of the same group.

Figure 2 presents analysis related to each half effort part. As can be observed (panel A), there were no differences in the total carry time of lifesavers and lifeguards in any condition. In Figure 2 (panel B), it may be observed that the use of fibre fins allowed for lifesavers to perform faster (in each middle part and for the total effort) comparatively with flexible fins. On the contrary, lifeguards attained similar \(v\) mean with both fin models. In barefoot condition, only in the first middle effort part, the lifesavers attained higher \(v\) than lifeguards.

Figure 2 (C) shows that the use of fibre fins by the lifesavers implies the rise of the \(v\) and fatigue inhibition during the first middle effort part. The decline of lifesavers \(v\) does not appeared to be, in general, different from the results observed for lifeguards. Figure 2 (D) reveals that fatigue induced by carrying is similar for both studied groups and conditions, and that the use of fibre fins help lifesavers to delay fatigue in the first middle part of the effort. The differences in results are very similar to the slope results, with the same punctual differences being observed. Ad-
dictionally, high SD values for FI are evident, showing a large individual variability among subjects.

DISCUSSION

Due to the high variability in fin models, a careful selection is required in order to increase performance or to facilitate rescue situations. As no study compared the performance obtained by lifesavers and lifeguards when using different fin models, the purpose of the study was to compare lifeguards and lifesavers when using flexible and fibre fins, which were compared also with the barefoot condition.

The observed higher v at the end of the 25m effort (final v) attained by lifesavers when using fibre fins could be due to the fact that they are commonly used in training and competition situations. Contrarily, fibre fins do not seem to be so often used in rescue situations, requiring lifeguards a more specific adaptation. This statement is only based on observation of the lifeguards’ behaviour in rescue scenes. The initial, mean and final segments vmean of lifesavers and lifeguards in the 25 m mannequin carry test were similar when flexible fins were used. The inexistence of differences in v attained by lifeguards using four different fin models was already pointed out by Abraldes et al. (2007). It is possible that the eventual lower training level of lifeguards compared to lifesavers did not allow for a specialized use of any of the tested fin models. Other possible explanation is that lifesavers usually carry dummies in standard events, and lifeguards carry real persons in real and unexpected circumstances.

Additionally, it is speculated that lifesavers revealed a higher level of technical carrying competence at the beginning of the barefoot effort, once they got a higher initial vmean. This difference in vmean between lifesavers and lifeguards observed in barefoot condition was not evident in the middle and final moments of the test. Regarding fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue related parameters, v decay and FI seen to be similar between lifesavers and lifeguards in the three conditions tested. This absence of differences could be a consequence of the short effort duration of the particular test used. Moreover, it can be explained by the inexact location of the point of exponential rise of fatigue. In the present study, the effort was divided in two parts, without the exact point of evident fatigue occurrence being determined. Future studies should focus on a more precise assessment of the point of fatigue appearance. Soares et al. (2006) have studied fatigue

CONCLUSIONS

Fibre fins allow a higher v of lifesavers when compared with flexible fins, but for lifeguards it is indifferent the type of fins used. The effect of the use of flexible or fibre fins is not evident in fatigue index both for lifesavers and lifeguards.

REFERENCES


Effect of Stroke Drills on Intra-cycle Hip Velocity in Front Crawl

Arellano R., Dominguez-Castells R., Perez-Infantes E., Sanchez E.

University of Granada, Granada, Spain

Competitive strokes have been widely analysed, while kinematics of co-ordinate drills, used to train or teach swimming techniques, have been scarcely studied. The aim of this work is to evaluate the differences in the intra-cycle hip velocity among freestyle swimming drills. Thirteen national and regional level swimmers performed five 25-m freestyle trials, using different stroke drills in a random order. The propulsive phase of each stroke was analysed. Mean and peak (one or two) velocity were obtained, and their corresponding phase percentage. The first peak recorded corresponded to the inward movement, which coincided with the final propulsion or downward movement of the opposite arm. The second one corresponded to the final backward-upward movement, which, in most cases, is the highest value of velocity while the non-propulsive arm is extended horizontally in front of the shoulder. The freestyle stroke drills applied to teach or train different types of inter-limb coordination reduce the mean and peak values of intra-cycle hip velocity while the percentage location of peak hip-velocity value during the underwater stroke phase is similar without significant statistical differences.

Key words: swimming kinematics, swimming technique.

INTRODUCTION

Current teaching and competitive swimming programs are composed of the correct combination of skill acquisition and conditioning exercises. Many swimming books or papers describe or classify these swimming exercises proposing guidelines to use them properly or in a skill assessment context (Goldsmith et al. 2007; Guzman, 1998; Laughlin & Delves, 1996; Maglischo, 2003; Sweetenham & Atkinson, 2003). The classifications used to include co-ordinate drills: arm-arm coordination, arm-breathing coordination and arm-leg coordination. Lately, arm-arm coordination drills have become very popular applied to develop the crawl-stroke swimming technique in master swimming, triathlon and competitive swimming while they are and are broadly used in the advanced learning stages of technique development in ‘learn to swim’ programs (Figueiredo et al., 2009; Seifert & Chollet, 2009).

While hip or centre of mass intra-cycle velocity has been studied in the current competitive strokes using observational or biomechanical methods (Barbosa et al., 2005; Figueiredo et al., 2009; Psycharakis et al., 2009), this has not been the case with the stroke drills applied to teach or train swimming technique. Stroke coordination, bi-dimensional or tri-dimensional kinematics, intra-cycle velocity, body-trunk rotation, stroke frequency and stroke length have been some subjects of study frequently applied to formal strokes but missed out in these drills. A first attempt was performed to analyse the differences in body rotation and 3D hand swimming path between freestyle swimming and one arm crawl stroke drills (López et al. 2002). Less body rotation and hand depth were found during the practice of formal one-arm and catch-up crawl stroke, while a modified one-arm stroke drill obtained similar values to that recorded during no breathing freestyle swimming.

The purpose of this study is to reveal the differences in intra-cycle hip velocity between formal front crawl and four other front crawl swimming coordination drills.

METHODS

Thirteen national and regional level swimmers (five males and eight females, aged 19.58±2.23) participated in this study as volunteers. All of them had trained in swimming for 6–8 years. Every participant had previous experience of the exercises. The protocol was fully explained to them and they provided written consent to participate in the study, which was approved by the university ethics committee. This investigation was performed in September, at the beginning of the competitive season. The characteristics of the participants are presented in Table 1.

Table 1. Anthropometric characteristics of participants in the study (n=13).

<table>
<thead>
<tr>
<th>Body mass (kg)</th>
<th>Height (cm)</th>
<th>Max. body length (cm)</th>
<th>Arm span (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD)</td>
<td>76.4 (10.5)</td>
<td>171 (7)</td>
<td>228 (11)</td>
</tr>
</tbody>
</table>

After a standard warm-up, swimmers randomly performed five 25-m freestyle trials, using a different stroke drill and no-breathing freestyle. They always started in the water and were instructed to swim as fast as possible, keeping to the stroke drill technique. All trials were performed during a specific testing session. Each participant performed every trial with a rest interval of more than 5 minutes (see Table 2 for stroke drill definitions).

Table 2. Stroke drills applied in the study.

<table>
<thead>
<tr>
<th>A</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-breathing formal freestyle swimming (reference technique)</td>
<td>One arm front crawl with the resting arm extended in front, breathing on the arm-moving side</td>
<td>One arm front crawl with the resting arm close to the body, breathing on the no-moving side</td>
<td>Controlled two-arm freestyle, swimmer perform arm-pull and arm-recovery simultaneously finishing each half cycle with one arm resting close to the body and the second one resting extended in front, kicking some seconds after each stroke</td>
</tr>
</tbody>
</table>

During each trial the swimmers’ time and intra-cycle velocity were recorded synchronized with underwater video recording. With this information, peak and mean velocity for each stroke (and its phases) were obtained.

The behaviour of the swimmers during the experiment was recorded with two underwater cameras, which were attached by a metal device to the lateral edge of the pool. Both cameras were placed 30cm below the water surface and were positioned 10 and 15m from the starting wall of the pool, respectively. The swimmers swam in lane 3, so that the cameras were able to record at least 15m of their performance from a lateral view.

An electronic timer connected to a touch pad was used to measure the swimmer’s times. Velocity was measured by a linear encoder, attached to the swimmers’ waist using a belt. The associated software enabled us to receive the data and videos in the computer in real time, ready to be processed through two USB 2.0 ports.

Velocity data were sampled at 200Hz and the video signal synchronized at 50 Hz. After selecting the stroke-phase sections of the videos, and before further processing, data were filtered using a Butterworth filter, with a cut-off frequency of 6 Hz.

For every participant, three strokes were selected and represented, in order to compare the velocity variations among them. A complete underwater stroke phase was considered from the beginning of the entry of the hand into the water until it was completely out. All the underwater stroke durations (100%) were normalized to a percentage scale, making it easier to compare strokes of different duration.

A statistical analysis was performed using Microsoft Excel 2007 and Statistica/Mac Plus 5.1. Then, the raw data was checked for normal distribution characteristics (p=0.96 for velocity). And finally, an analysis of variance with repeated measures was applied to determine variability between exercises using Scheffe post-hoc tests for intra-group comparisons.
RESULTS

Mean values of 25m-velocity and 25m-performance for every swimming drill were obtained (see Table 3). The recorded times and mean velocities were slower in all the swimming drills compared with the no-breathing freestyle (p<0.05), while the stroke drill times and mean velocities did not show statistical differences among them after performing the Scheffé post-hoc tests.

Table 3. Mean and SD of velocities (v) and records (t) for each swimming drill

<table>
<thead>
<tr>
<th>Swimming Drill</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 25m-v (m/s)</td>
<td>1.64</td>
<td>1.10*</td>
<td>1.08*</td>
<td>1.07*</td>
<td>1.00*</td>
</tr>
<tr>
<td>SD</td>
<td>0.22</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.14</td>
</tr>
<tr>
<td>Mean 25m-t (s)</td>
<td>15.50</td>
<td>20.38*</td>
<td>23.77*</td>
<td>24.06*</td>
<td>25.47*</td>
</tr>
<tr>
<td>SD</td>
<td>3.32</td>
<td>12.96</td>
<td>4.18</td>
<td>4.14</td>
<td>3.34</td>
</tr>
</tbody>
</table>

* p<0.01 between A and B, C, D and E.

Two velocity peaks in 33.8% of the exercises analysed were found (Figure 1) during the backward movement of the hand in the underwater propulsive phase. The other exercises had only one peak, which appeared in the last third of the underwater stroke phase. However, representations in Figure 1 contain 2 and 3 peaks, respectively. This is because the first one in each case corresponds to the end of the previous stroke, which coincides with the beginning of the current stroke. Therefore, it will not be considered in the analysis. From the exercises with two peaks, 40.9% were during the no-breathing front crawl. In formal freestyle, this may slightly increase propulsion. The second one is at 75.99%. In 64.71% of the exercises with one peak, it corresponds to the pull phase (inward movement), which coincides with the final propulsion or downward movement of the opposite arm. This may slightly increase propulsion. The second peak corresponds to the final backward-upward movement, which is in most cases the highest value of velocity while the non-propulsive arm is extended horizontally in front of the shoulder.

The average percentage of peak 1 is located at 62.5% while the second one is at 75.99%. In 64.71% of the exercises with one peak, it corresponds to the final pull movement. Velocity peak values and their corresponding phase percentages can be seen in Table 3.

Table 3. Mean and SD of peak velocities and corresponding percentages for the different drills.

<table>
<thead>
<tr>
<th>Drill</th>
<th>n</th>
<th>% 2nd Peak</th>
<th>Mean (DT)</th>
<th>V 2nd Peak</th>
<th>Mean (DT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12</td>
<td>69.90*</td>
<td>(27.33)</td>
<td>2.06</td>
<td>(0.16)</td>
</tr>
<tr>
<td>B</td>
<td>13</td>
<td>76.90*</td>
<td>(22.53)</td>
<td>1.41</td>
<td>(0.07)</td>
</tr>
<tr>
<td>C</td>
<td>11</td>
<td>83.10*</td>
<td>(17.02)</td>
<td>1.38</td>
<td>(0.08)</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>80.99*</td>
<td>(16.69)</td>
<td>1.14</td>
<td>(0.09)</td>
</tr>
<tr>
<td>E</td>
<td>13</td>
<td>69.06*</td>
<td>(17.42)</td>
<td>1.26</td>
<td>(0.07)</td>
</tr>
</tbody>
</table>

* p<0.01 between A and B, C, D and E

DISCUSSION

Peak and mean velocities were higher in crawl-stroke swimming (A) than in the rest of the drills. These results can be explained by the lack of continuity of stroke propulsion during the stroke drills studied. These differences were not found in the percentage duration of the underwater pull phase where the peak velocity value was located. The intralimb coordination changes produced by the stroke drills applied did not interfere with the location of hip peak velocity percentage during the underwater pull phase. Excluding the reference no-breathing stroke, the different stroke drills with relevant inter-limb changes did not differentiate the peak velocity value between drills.

The first peak assessed corresponds to the pull phase (inward movement), which coincides with the final propulsion or downward movement of the opposite arm. This may slightly increase propulsion. The second peak corresponds to the final backward-upward movement, which is in most cases the highest value of velocity while the non-propulsive arm is extended horizontally in front of the shoulder.

Similar studies, where shoulder rotation was measured found that the drill (D) (López at al. 2002) obtained similar rotation angles than no-breathing freestyle. This situation did not occur when the variable analysed is the intra-cycle hip velocity.

CONCLUSIONS

The freestyle stroke drills applied to teach or train different types of inter-limb coordination reduce the mean and peak values of the intra-cycle hip velocity. Meanwhile the percentage location of peak hip-velocity value during the underwater stroke phase is kept similar without significant statistical differences. Considering the differences in body trunk rotation found in our previous studies, coaches should carefully consider the application of these drills during training due to the additional effect on the hip intra-cycle velocity that is decreased during their practice. Additional work to study the effect of their practice on formal freestyle performances should be done. On the other hand, the similar path of the intra-cycle hip velocity found in all the drills compared to formal freestyle may be a positive aspect that merits further study.

REFERENCES


ACKNOWLEDGMENTS

This study and its presentation were partially financed by: A) Secretary of State for Research, Ministry of Science and Innovation. Call for Basic/Fundamental Research Projects, December, 31, 2008. Ref. DEP2009-08411. “Study of Swimming Propulsive Movements [sculling] using 3D Analysis, Fluid Visualization, CFD and PIV”. B) The support program of subject practices of the University of Granada, coordinated by Physical Education and Sports Department and the Research Group of Physical Activity and Sports on Aquatic Environment [CTS.527]. Special thanks to the swimmers for their cooperation.

The Usefulness of the Fully Tethered Swimming for 50-m Breaststroke Performance Prediction

Barbosa A.C.¹, Milivoj Dopsaj M.², Okicic T.¹, Andries Junior O.¹

¹Faculty of Physical Education, Campinas State University, Sao Paulo, Brazil
²Faculty of Sport and Physical Education, Belgrade University, Belgrade, Serbia
³Faculty of Sport and Physical Education, Nis University, Nis, Serbia

The present study aimed to identify the relationship between 50-m breaststroke performance and force-time variables obtained from a 30-s maximal tethered swimming test. Fourteen high-competitive male breaststrokers from Brazil and Serbia accomplished a 30-s maximal breaststroke effort in tethered swimming. The mean value of peak force, average force ($F_{avg}$), impulse force ($I_{imp}$), rate of force development and full stroke duration ($DUR$) was retained for analysis as independent variables. Time in 50m breaststroke, obtained in long course competition, was converted in average swimming velocity ($VEL_{avg}$) to be used as dependent variable. Multiple regression analysis with the backward method was employed to construct the model, which was statistically significant ($F=29.933$, $p<0.001$), explaining 82.1% of sample size adjusted variance ($r^2=0.821$) with a standard error of $\pm 0.015$ m/s and represented the equation: $VEL_{avg} = 3.401 - 0.002*DUR + 0.015*I_{imp} - 0.015*F_{avg}$. These results showed that breaststroke swim velocity is highly related to an associated behaviour of some force-time curve's variables, i.e., the impulse of force, average force and stroke duration.

Keywords: Tethered Swimming, Breaststroke, Performance, Multiple Regression Analysis

INTRODUCTION

Propulsive force is well recognized as an important component of swimming performance and one of the most used method for its evaluation is the fully tethered swimming (Adams et al., 1983; Bollens et al., 1988; Cabri et al., 1988; Dopsaj et al., 2000; Dopsaj et al., 2003; Lutomsky et al., 2008; Moruço et al., 2008; Papoti et al., 2003; Papoti et al., 2007a; Papoti et al., 2007b; Yeater et al., 1981). Despite of its metabolic and electromyography similarities with the conventional swimming (Bonen et al., 1986; Bollens et al., 1988; Cabri et al., 1988), high reliability (Dopsaj et al., 2003; Papoti et al., 2003) and training sensitivity (Papoti et al., 2007b), most of these studies was focused on crawl-stroke. Thus, it is still unclear whether or not tethered swimming can be used to evaluate others strokes. Besides, considering the lack of information concerning elite swimmers, researches developed with them are needed.

The purpose of this study was to identify the relationship between elite breaststrokers’ 50-m performance and force-time curve’ variables accessed through a 30-s maximal tethered swimming test. It was hypothesized that swim velocity may be related to propulsive force as measured by using a tethered swim protocol and also that inter-individual differences in swim velocity while swimming breaststroke are related to tethered swim variables.

METHODS

The sample was composed by 14 high-competitive male breaststrokers (age: 22.50 ± 5.00 years, height: 1.83 ± 0.09 cm, weight: 76.3 ± 7.4 kg, percent from 50-m breaststroke long pool World Record: 91.91 ± 1.91%) from Brazil and Serbia. Prior to data collection, written informed consent was obtained from the participants. The procedures were approved by institutional ethics committees from both countries.

Propulsive force was obtained through the fully tethered swimming
(Dopsaj et al., 2000; Dopsaj et al., 2003). The 2000 N load cell had 4 attached strain gauges and an accuracy of 30 g. One of its extremities was fixed to a special designed support, attached to the starting platform or to the pool border, while the other was connected to an inextensible cable, in which swimmer was tethered. Mechanical deformations in the load cell, generated by swimmer's efforts, were recognized by an A/D interface, which converted the analogue voltage in a digital signal. In sequence, the force values were obtained through the calibration straight line. The minor acquisition frequency used was 200 Hz. Raw data was low-pass filtered with a cut-off frequency of 8 Hz. The system was calibrated using increments of 5 Kg until the maximum weight of 50 Kg. It was checked before every testing session using a weight of 10 Kg.

As warm-up, swimmers performed a 10-minute active stretch and 15 minutes of free swimming. After, a specific procedure described earlier (Dopsaj et al., 2000) was conducted in order to get swimmers familiarized with the equipment.

![Figure 1](image1)

**Figure 1.** Example of a typical force-time curve during the 30-s tethered test

As test protocol, the swimmers accomplished a 30-s self-chosen cycle frequency maximal breaststroke effort in tethered swimming, whereas the beginning and the end were signalized by a whistle. In order to minimize the effects of swimming intensities transition, the first second swim maximally was discarded. A typical f-t curve obtained in the test protocol is shown in Figure 1. Main points of force-time curve in a complete were marked, as shown in Figure 2.

![Figure 2](image2)

**Figure 2.** Visualization of the determinant points used in the force-time curve's analysis. Fpeak: Peak force; ImpF: impulse of force represented by the curve’s area; Fmin1 = beginning of the stroke; Fmin2 = end of the stroke; \(\Delta t\) = time variation; \(\Delta F\) = force variation.

Through these points, five independent variables were extracted, as follows: 1) Peak force (Fpeak), represented by the maximum force value found in a complete stroke, expressed in N. 2) Average Force (Favg), represented by the average of all force values found in a complete stroke, i.e., between minimum force 1 (Fmin1) and 2 (Fmin2), expressed in N. 3) Impulse Force (ImpF), represented by force-time curve's area found in a complete stroke, i.e., between Fmin1 and Fmin2, expressed in Ns. Integration was made using the trapeze method. 4) Stroke Explosiveness (RFD), represented by the rate of force development (RFD) in a complete stroke, expressed in N/s. RFD was calculated using the equation: \(\text{RFD} = \frac{\Delta F}{\Delta t} \times 1000\), where \(\Delta F = F_{\text{peak}} - F_{\text{min1}}\) expressed in N and \(\Delta t = \text{Time value when Fpeak was reached - time value found in Fmin1}\), expressed in ms. 5) Full Stroke Duration (DUR), represented by the difference between time values found in Fmin2 and Fmin1, expressed in ms.

The variables’ value retained for analysis was the average of all movement cycles executed during the test protocol. Time in 50m breaststroke, in different moments of the periodisation, obtained in competitive conditions, two weeks before or after the tethered test, was converted in average swimming velocity (VEL50m), to be used as dependent variable.

Mean (\(\bar{X}\)), standard deviation (SD), minimum (Min), maximum (Max) and coefficient of variation (CV) were used as basic descriptive statistics. The relationship model was established through Multiple Regression Analysis (MRA) with the Backward Elimination Method. An equation of the regression model was generated using the variables being statistically significant and most accurately described the criterion. All statistical analysis was conducted using SPSS for Windows (Version 16.0, SPSS, Inc., Chicago, IL). The significance level was set at 95% (p<0.05).

**RESULTS**

Basic descriptive statistics of VEL50m, Fpeak, Favg, RFD, DUR are presented in Table 1.

![Table 1](image3)


<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ((\bar{X}))</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VEL50m (m/s)</td>
<td>1.72</td>
<td>0.04</td>
<td>1.66</td>
<td>1.78</td>
<td>2.07</td>
</tr>
<tr>
<td>Favg (N)</td>
<td>469.82</td>
<td>94.61</td>
<td>347.49</td>
<td>705.11</td>
<td>20.14</td>
</tr>
<tr>
<td>Fpeak (N)</td>
<td>136.92</td>
<td>17.54</td>
<td>107.38</td>
<td>163.86</td>
<td>12.81</td>
</tr>
<tr>
<td>ImpF (Ns)</td>
<td>156.52</td>
<td>14.37</td>
<td>125.51</td>
<td>187.89</td>
<td>9.18</td>
</tr>
<tr>
<td>RFD (Ns)</td>
<td>1147.61</td>
<td>464.55</td>
<td>584.59</td>
<td>2295.36</td>
<td>40.48</td>
</tr>
<tr>
<td>DUR (ms)</td>
<td>1157.65</td>
<td>125.89</td>
<td>1029.11</td>
<td>1418.33</td>
<td>10.88</td>
</tr>
</tbody>
</table>

Results from ANOVA regression showed that the model was statistically significant (F=29.933, p<0.001) and can explain 92.9% of the dependent variable common variance (\(r^2=0.929\)) or 92.1% of the sample size adjusted variance (adjusted \(r^2=0.821\)). The standard error of estimation was 0.015 m/s, which corresponds to ±0.74s in the final time. The model structure was saturated with three variables (Table 2), namely: full stroke duration (DUR), impulse force (ImpF) and average force (Favg); used to establish the equation for elite sprint breaststrokers’ performance prediction:

\[
\text{VEL}_{50m} = 3.401 - 0.002 \cdot \text{DUR} + 0.015 \cdot \text{ImpF} - 0.015 \cdot \text{Favg}
\]

![Table 2](image4)

**Table 2. Multiple Regression Analysis**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>S.E. (m/s)</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3.401</td>
<td>0.331</td>
<td>10.281</td>
<td>0.000</td>
</tr>
<tr>
<td>DUR</td>
<td>-0.002</td>
<td>0.000</td>
<td>-5.849</td>
<td>0.000</td>
</tr>
<tr>
<td>ImpF</td>
<td>0.015</td>
<td>0.002</td>
<td>6.257</td>
<td>0.000</td>
</tr>
<tr>
<td>Favg</td>
<td>-0.015</td>
<td>0.003</td>
<td>-5.643</td>
<td>0.000</td>
</tr>
</tbody>
</table>

DISCUSSION

The present results showed a high significant relationship between 50-m breaststroke performance and tethered swimming test, corroborating to previous study, which observed the same for high competitive crawl-strokers (Dopsaj et al., 2000), and confirming the initial hypothesis that breaststroke swim velocity is related to tethered swim variables. The current equation for performance prediction was composed by three variables. The stronger partial relation with 50-m breaststroke performance was find at impulse of force (ImpF, t value = 6.257), than at full stroke duration (DUR, t value = -5.849, and finally at average force (Favg, t value = -5.643). Basically, a lower DUR and Favg correspond to full stroke duration (DUR, t value = -5.849, and finally at average force (i.e., the increase of the stroke rate) would cause a strong diminishment in the effective time of force production. Indeed, it highlights the importance of the streamline position during the gliding phase, which is said to be determinant for breaststroke performance (Takagi et al., 2004).

The negative relationship of Favg is possibly related to a greater gliding time adopted by the most qualified breaststrokers (Takagi et al., 2004), which would cause a diminishment in the effective time of force production. Besides, the present equation pointed out an inverse relationship between DUR and swimming performance in 50m breaststroke specifically, signaling that the decrease of full stroke duration (i.e., the increase of the stroke rate) would cause a stronger gliding rhythm and consequently a greater swimming velocity.

The participation of DUR in the model can still be stronger due to its effect on ImpF calculation. The ImpF, already considered in a previous crawl-stroke model (Dopsaj et al., 2000), represents the working potential to be realized in conventional non-tethered swimming. Consequently, its positive relationship is reasonable and highlights the necessity of finding the proper training loads and methods which could improve this variable significantly. Besides, as a result of the curve’s area, it is basically affected by five main factors: (1) Fpeak: establish the maximum height reached in the curve; (2) RFD: determine the inclination of the curve before the Fpeak; (3) “relaxing” phase: determine the inclination of the curve after the Fpeak; (4) DUR: represent the base of the curve; (5) gliding time: determine the time of the curve which will be with no height, i.e., without force production and consequently null impulse. Thus, the decrease of DUR should be associated to an increase of ImpF even though this relation is apparently concurrent.

Thus, despite of the critics about technique modifications, essentially due to the hydrodynamics limitations caused by the null velocity, the tethered swimming usefulness was confirmed by the current model, allowing breaststroke performance prediction with 82.1% of confidence and an error of ±0.74s, even though high competitive breaststrokers were used. Besides, differently from a simple time measurement, the tethered swimming method allows the assessment of the propulsive force variables and, consequently, to understand how much different each one is involved with swimming performance, what variables are needed to be improved for getting better results and, after testing swimmers at different moments of the periodisation, identify deeper how the different training loads administrate are influencing performance in 50m breaststroke.

CONCLUSION

It can be concluded that elite breaststrokers’ 50-m performance is highly related to an associated behaviour of some force-time curve’s variables, i.e., the impulse of force, average force and stroke duration. Therefore, tethered swimming can be used as an important tool not only for crawlers, as previously reported (Dopsaj et al., 2000), but also in sprint breaststrokers.

REFERENCES


ACKNOWLEDGEMENTS

Authors would like to thank CAPES for the financial support, CEFISE for the tethered swimming system used in Brazil and coaches Flávio Lopes and Carlos Mathes for the scientific cooperation.
Joint Torque Request for Different Fin Uses

Gouvernet, G. 1,2, Rao, G. 2, Barla, C. 1, Baly, L. 1, Grélot, L. 2, Berton, E. 3

1Oxylane Research, Lille, France
2Institut des Sciences du Mouvement "E.J. Marey", Marseille, France

The purpose of the present study was to examine the joint torques of different fin swimming activities using different fins. Three different fin uses were in focus: body-board, swimming, and snorkelling. Inverse dynamics was used to estimate the joint torque of the lower body joints (knee and hip). For each practice we recorded the three-dimensional kinematics with underwater camcorders. Apart from the kinematics inputs, the forces and torques were measured by a robot which reproduced mean kinematics of each practice and measured the forces and torques components at the ankle. Thus, joint torques was measured at the ankle and computed at the knee and hip joints. Joint torque pattern and peak values differed for the ankle and knee joints but were not statistically different at the hip whatever the practice. This method allows to measure forces and torques on ankle and in this way precisely quantify the effect of fin blade on human joints.

Keyword: Swimming-fin, Fin, Muscular request, Snorkelling, Body-board

INTRODUCTION

Depending on the fin sport, swimmers expectations are not the same (acceleration, endurance, or muscular gain). Therefore, fin design with a specific shape and material has been designed for each specific sport.

For the last few years, sophisticated numerical model have enabled for modelling propulsive and drag forces for a swimmer without fins. The numerical model (SWUM) of Nakashima (2007) considers a full-body musculoskeletal model guided by different kinematics of swimming styles (craw, breast) and compute global swimming forces. But this last model regards segments as rigid bodies, and the fin blade cannot be simplified as rigid part. Thus, this previous model can not be used to quantify the effect of a deformable fin blade.

Moreover, at the same speed, swimming with a large and stiff fin blade requires less energy than with a short and flexible fin (Zamparo 2006). So, fin structure (shape and stiffness) entails a modification of fin forces on foot and consequently of the energetic expenditure. The aim of this study was thus to investigate the influence of different fin types on joint torques during fin swimming activities.

METHODS

In order to assess joint torque, an inverse dynamic model is used where joint kinematics and hydrodynamics fin forces have to be described for each activity.

Mean kinematics of each fin swimming activities were determined from experimentation. Six male and 2 female skilled participants of all activities were asked to practice the three activities in usual conditions. Subject’s average (±SD) body mass, stature, and age were respectively 71±7.2 kg, 1.73±0.13 m, and 27±3.2 years. For swimming, subjects swim holding out their arms on a board, and their heads in water. Body-.boarders were told to adopt the same velocity as when they go to the swimming pool. The picture definition allowed a good precision of tracking. The three-dimensional positions were computed by the DLT method (SIMI Motion Systems GmBH, Germany). Data were smoothed using a Butterworth lower pass filter at 6Hz. During each swim, three cycles were selected. The cycles were cut at the highest position of the subject’s foot. Then, the cycles were averaged to obtain a representative kinematical cycle per subject per and swimming activities (body-board, swimming, or snorkelling).

For each activity recorded, the foot motions averaged over the subjects were reproduced using a custom-made robot. This twice-fin robot reproduces the kinematics of the two feet by velocity control. Ankle angle and vertical kicking were controlled (Figure 2). Also, the distance of the robot from the water surface could be adjusted, in order to reproduce the good kicking depth too. The foot motion on sagittal plane was used as an input parameter of the robot. A waterproof six-component sensor is located on the foot form of the robot, at the same position as the ankle joint; in this way forces and torques produced by fin on foot are measured. Moreover, the robot moved forward at the velocity measured in each fin swimming activities. Thus, sagittal ankle motions reproduced the foot motion of each activity with a matching velocity. This simulation of fin swimming activities allowed us to consider measured forces as close to real forces encountered during swimming as possible.

Three-dimensional force and torque measurements were made on the foot robot which reproduced mean motion of each activity. Inverse dynamics computations were carried out to estimate the three-dimensional net forces and torques at the knee and hip joints. Net joint moments were estimated taking into account gravity, inertial body parameters, as well as Archimedes thrust (FA=pVg), the volume (V) being assessed as a function of body mass and segment density (Zatior-sky 1990). This force was applied at the segment centre of mass.

Both swimming (frequency, amplitude and depth of the kick), and muscle torque variables were analyzed.

Figure 1. Fins for body-board (a), swimming (b), and snorkelling (c).
RESULTS

Kick amplitudes did not appeared as a significant parameter (p>0.05). However, snorkelling kicks substantially differed in frequency and depth. Snorkelling frequency was lower than the two others practices (Table 1). This last result agrees with measurement made with different snorkel fins by Zamparo et al. (2006). The kick depth, defined as the higher position of ankle during a cycle, showed snorkelling depths closer to the water surface than swimming and body-board values.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Frequency (Hz)</th>
<th>Amplitude (m)</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swimming</td>
<td>1.01 ± 0.17</td>
<td>0.42 ± 0.02</td>
<td>-0.16 ± 0.08</td>
</tr>
<tr>
<td>Snorkelling</td>
<td>0.85 ± 0.19</td>
<td>0.36 ± 0.02</td>
<td>0.02 ± 0.26</td>
</tr>
<tr>
<td>Body-board</td>
<td>0.98 ± 0.18</td>
<td>0.42 ± 0.02</td>
<td>-0.08 ± 0.08</td>
</tr>
</tbody>
</table>

Concerning the inverse dynamics results, torques values gradually increased from the ankle to the hip joint. For all joints, the highest amplitude was found around the flexion/extension axis.

The robot reproduces seven stock swimming cycles with a standard deviation lower than 4%. On the ankle joint, amplitude patterns are lower for body-board. In knee and hip torque amplitudes, no difference were found between the three activities. Forces and torques patterns measured on the ankle sensor of the robot showed only one oscillation.

The torque pattern computed by the model described a double oscillation during stroke cycle, both in the knee and the hip (Figure 3). In the knee joint, during the snorkelling activity, the second upper peak disappeared, because value of this peak staid negative while the two others were positive, as well as in the second lower peak for body-board activity on knee. In the hip joint, the oscillations were synchronous but snorkelling amplitudes were lower than others.
DISCUSSION
These results must be carefully considered because variability increases at each proximal joint. This increase in variability may explain the absence of significant difference in amplitude between activities at the hip joint, despite graphical proof. The inverse dynamic model allows us to compute knee and hip torques. But modelling torques show a double oscillation whereas measured torque on ankle shows a single oscillation. The first half cycle of swimming activities is the down kick of foot and first a positive, then a negative torque on the knee can be observed. Probably the drag forces of each segment were underestimated, which needs further research.

Fin swimmer kinematics is influenced by the body position during fin swimming activities. For each fin swimming activity, kick frequency and amplitude are different but also depth of the kick foot. Thanks to this new method, we can assess to three-dimensional forces and torques on the ankle for the three fin swimming activities. These three practices show main differences in amplitude but not in the timing pattern.

CONCLUSION
This method has the main advantage of allowing us to measure the effect of fin blade on ankle joint, and also to compute the amount of torque on the knee and hip. However, the muscular capacity of the subjects as a function of both the swimmer level and fin swimming activities needs to be clarified.

REFERENCES

3D Computational Fluid-structure Interaction Model for the Estimation of Propulsive Forces of a Flexible Monofin
Bideau, N. 1, Razafimahery, F. 1, Monier, L. 1, Mahiou, B. 1, Nicolas, G. 2, Bideau, B. 2, Rakotomanana, L. 3

1 Institut de Recherche Mathématique, University of Rennes 1, Rennes, France
2 M2S, University of Rennes 2, Rennes, France
3 For the Estimation of Propulsive Forces of a Flexible Monofin

The goal of this study was to analyse the dynamic performance of a monofin for a given kinematics. The problem is formulated within the framework of a 3D fluid-structure interaction model. The numerical solution is computed using the finite element method. Namely, the role of the added mass is highlighted by the modal analysis of the coupled problem. Moreover, instantaneous propulsive forces and torques are calculated. Both qualitative and quantitative results were obtained. In particular, the effect of its deformability and the influence of added mass are pointed out.

Key words: Monofin, Propulsion, Finite Elements, Fluid-Structure Interaction

INTRODUCTION
The current paper contributes to the investigations of biomechanical aspects of propulsion in monofin swimming. The estimation of the dynamical response of the fin is one of the key points of the performance in monofin swimmers. This can be achieved through dynamic measurement or modelling. Throughout the history of swimming research, different attempts have been made to measure accurately the propulsive forces, using experimental or modelling approaches. The dynamic understanding in monofin-swimming motion was introduced by Rejman (1999) from an experimental point of view. Using strain gauges glued on each side of the fins surface, the author put in relation the local forces during up and down motions with swimming speed. However this approach is not sufficient to describe the flow over the fin. More recently, (Zamparo et al., 2005) used a methodology previously applied to fish locomotion to calculate efficiency for fin swimming at low speeds. While energy flows were precisely quantified, it remains very difficult to evaluate the influence of the fin on global performance. To compensate for this drawback, recent approaches based on computational modelling can be used. In that sense, two major approaches have been proposed in the literature. The Finite Element Method (FEM) has been intensively used to model the foil and swimmer dynamics (Von Loebbecke, 2009). Most of them, based on Computational Fluid Dynamics (CFD) neglected the elasticity of the foil. Indeed, no constitutive law is considered for the structure. Some authors have studied the mechanical properties of fin without fluid (Bideau et al., 2003). To our knowledge, there is no study considering de dynamical behaviour of the whole continuum model (solid and fluid features at the same time). In this paper, a new method that is devoted to computation of propulsive forces generated by a flexible monofin is described. From this method, the added mass is calculated, and shows the great impact of this parameter.

Figure 1. Example of the mesh of the solid domain (monofin) and the fluid domain (pool) used in the FEM simulation
METHODS
A three-dimensional model of the fin-water system is proposed which is built on the following assumptions. Based on continuum theory, a fluid-structure interaction is developed with inertial coupling. The system is depicted in Figure 1 and is composed of a solid domain ($\Omega_s$) coupled with a surrounding fluid domain ($\Omega_q$). The boundary ($\Gamma$) corresponds to the deformable fluid-structure interface. The external excitation for the stroke motion (i.e. the rate of undulation) is assumed to be lower than the wave speed in the fin, so that the fluid can be described with the acoustic pressure (Morand and Ohayon, 1995). It corresponds to an undulatory type of low frequency swimming. The fin is assumed to be a deformable elastic structure. Namely, the monofin is modelled using a multilayer structure, whose constitutive law is written by means of the Cauchy stress tensor $\sigma$. The imposed kinematics at the leading edge of the monofin (that corresponds to the swimmer’s ankle) results in a volume force $\gamma_n$. If we denote by $u$ the displacement field of the monofin and $p$ pressure field within the fluid domain, the problem consists in finding $(u,p)$ solutions of the following three-dimensional boundary value problem:

$$\nabla \cdot \sigma + \gamma_n = 0 \quad (\Omega_s) \quad (1)$$

$$\sigma = -p n \quad (\Gamma) \quad (2)$$

$$\begin{bmatrix}
\frac{\partial \sigma}{\partial x} & \frac{\partial \sigma}{\partial y} & \frac{\partial \sigma}{\partial z} \\
\frac{\partial \sigma}{\partial y} & \frac{\partial \sigma}{\partial x} & \frac{\partial \sigma}{\partial z} \\
\frac{\partial \sigma}{\partial z} & \frac{\partial \sigma}{\partial y} & \frac{\partial \sigma}{\partial x}
\end{bmatrix} \nabla \cdot \sigma + \gamma_n = 0 \quad (\Omega_s)$$

$$\begin{bmatrix}
\frac{\partial p}{\partial x} \\
\frac{\partial p}{\partial y} \\
\frac{\partial p}{\partial z}
\end{bmatrix} = 0 \quad (\Gamma) \quad (4)$$

$$\gamma_n = \begin{cases} 0 & (t) \\ \gamma_n & (\text{ne}) \\ 0 & (\text{m}) \\ \gamma_n & (\text{me}) \\ 0 & (\text{e}) \end{cases}$$

Where $\nabla \cdot \sigma$ is the velocity field in the fluid, $\rho$ is the density of the monofin, $\rho_0$ is the fluid density and $n$ is the outward unit normal to the fin domain. The coupling results in a new term in the inertial contribution of the system. Indeed, this added mass characterizes the energy transmission between the fin and the water. The specificity of the present method is that the temporal evolution of dynamical features is available. Namely, transient added mass, three-dimensional forces and torques at the point corresponding to the swimmer’s ankle as well as energy balance are obtained. Since this resulting fluid-structure interaction problem is too complex to be solved analytically, we analyzed using the means of numerical approximation. We will briefly outline the solution methodology used to solve the governing equations. The latter are solved with the Finite Element Method using the commercial software COMSOL Multiphysics (Comsol Inc., Burlington, USA). Numerical simulations are carried out for the fluid flow in a pool with the following dimensions: In the pool, a fin with realistic dimensions (0.80 m chord and 0.50 m wide) is located at the distance of 5 m from left wall. In this study a monolithic approach is used. Indeed, the equations governing the fluid flow and the displacement of the structure are solved simultaneously with single solver. The main steps of the methodology are the following: first, based on realistic pictures, the geometry of the monofin is created. The resulting volume, which is the form of an Initial Graphics Exchange Specification (IGES) file format, is then input into the commercial software COMSOL Multiphysics and transformed to an unstructured volume mesh with triangular elements. The second step consists in the meshing. The final volume mesh (Figure 1) consists of 6256 triangular elements for the fin and 128676 triangular elements for the water. The third step consists in a modal analysis of the three-dimensional coupled problem. $\gamma_n$ is set to zero and a time harmonic solution of the problem is computed. This allows obtaining the fundamental vibration characteristics of the immersed monofin and therefore the quantitative and qualitative effect of the added mass can be pointed out. The final step of the methodology consists in a transient analysis of propulsive forces. Thus, in the numerical experiments that are presented, the monofin is undergoing time-dependent motion that combines translating and rotating motions as follows:

$$\alpha(t) = \frac{\theta_0}{\theta_0} \sin(\omega_0 t + \psi)$$

$$h(t) = \frac{\theta_0}{\theta_0} \sin(\omega_0 t)$$

with

$$\omega_0 = 1.7 \text{ rad s}^{-1}$$

$$\theta_0 = \frac{\pi}{4} \text{ rad}$$

$$\psi = \frac{\pi}{2} \text{ rad}$$

$$h_0 = \frac{3 c}{4}$$

in which $c$ is the chord of the monofin. In the numerical experiments, $c$ is set to 0.7m. The material properties used in the FEM simulation are given in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>$E$ [Pa]</th>
<th>$V$</th>
<th>$\rho$ [kg m$^{-3}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon 12K</td>
<td>146.10$^9$</td>
<td>0.32</td>
<td>1565</td>
</tr>
<tr>
<td>Low density Polyethylene</td>
<td>146.10$^9$</td>
<td>0.38</td>
<td>920</td>
</tr>
<tr>
<td>Rubber</td>
<td>0.0510$^9$</td>
<td>0.49</td>
<td>1250</td>
</tr>
</tbody>
</table>

Table 1. Material characteristics used in the FEM simulation. $E$ is the Young’s modulus, $V$ is the Poisson’s coefficient and $\rho$ is the density of the monofin. (Data provided by Breier SAS company)

Some of the key parameters associated with the performance of the monofin are the lift force $L$, the thrust force $T$ (equal to negative drag force $D$) and the resulting torque at the swimmer’s. Thanks to the present FEM method, the accurate efforts (resulting force and resulting torque) at the point O, which corresponds to the swimmer ankle, are computed. The instantaneous resultant force components are calculated by directly integrating the traction vector on the fin surface. In particular, if $\sigma$ is the stress tensor and $n$ is the outward normal unit to the fin surface A, the resultant force is given by

$$R(t) = \int \sigma n d\Gamma = L(t) x + T(t) z$$

where $T(t)$ and $L(t)$ are the instantaneous thrust force and instantaneous lift force respectively. It known that the performance of flexible fins depends largely on the effective dynamic properties of the structure. Therefore, modal analysis was performed in this work. This allowed for the quantification of the added mass effect on the fin by comparing the natural frequencies and modal shapes in the case where the fin is submerged or not. The first natural frequencies $f_i = \lambda_i / 2\pi$ are reported in Table 2. In this study transient force and torque at the swimmer’s ankle is computed. Figure 3 shows the variation of the thrust.

Table 2. Comparison of first natural frequencies $f_i = \lambda_i / 2\pi$ [Hz] obtained with the Coupled FEM.

<table>
<thead>
<tr>
<th></th>
<th>$f_1$</th>
<th>$f_2$</th>
<th>$f_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D in water</td>
<td>6.08</td>
<td>41.12</td>
<td>70.03</td>
</tr>
<tr>
<td>3D in vacuum</td>
<td>13.01</td>
<td>113.51</td>
<td>256.34</td>
</tr>
<tr>
<td>3D in water</td>
<td>4.395</td>
<td>23.87</td>
<td>41.87</td>
</tr>
</tbody>
</table>
There is a significant difference between the modal shapes of rigid fin model and that of flexible fin model. This highlights the necessity of accounting as accurately as possible not only the fluid-structure interaction but also the deformability of the elements during a propulsion analysis of a fin. Modal shapes of the immersed fin are not the same as those of the dry fin case. This is due to the non-symmetry of the added mass matrix. Therefore, including the effect of coupling between the fin and the surrounding water is essential for an accurate description of the dynamic behaviour of flexible fins. Moreover, this feature is an important parameter in the design of optimal swim fin especially for competitive swimmers. If we compare the eigenfrequencies obtained with the present model with those obtained with the corresponding two-dimensional model (Bideau et al., 2009), it can be observed that taking into account for three-dimensional effects leads to a decrease of the deformation of the fin. This can be explained by the fact that the three-dimensional model is less constrained than the two-dimensional one, which allows more flexibility in the third direction. Indeed, two-dimensional shapes can only take into account for the in-plane flexion. As an example, the third modal shape of the monofin blade is depicted on figure 2. On the same figure, the pressure field of the fluid is plotted at time t=1.5s. In fact, the pressure is being examined to better understand the generation of thrust. The temporal evolution of those variables tends to an oscillating behaviour when increasing the rigidity of the fin plate. It can be noticed that there is a significant variation of the frequency of the thrust evolution in regards to the applied stroke kinematics that are harmonically varying. This can be explained by the elasticity of the flexible fin. The elastic energy is stored in a first time and distributed in a second part. Therefore, the strain energy of the structure is seen to greatly affect the propulsive characteristics (propulsive force and resulting moment) of the monofin (Figure 3).

CONCLUSION

A 3D fluid-interaction model has been presented. It is based monolithic resolution of the whole system fluid and solid. The present work investigated the properties of propulsive force of a three-dimensional deformable monofin. In particular, the added mass effect of the coupled dynamics has been pointed out. The transient propulsive force end torque computation has been investigated by means of FEM method. The influence of the elasticity (i.e. strain energy) has been investigated and shows that he flexibility of the fin blade increase the thrust. To our knowledge it is the first fluid-structure interaction model for the whole monofin-water system solved by 3D FEM approach.

REFERENCES


The aim of this study was to compare the effect of Fastskin swimsuits (FS) on spatio-temporal parameters, IdC and propulsive phases (PP) in front crawl swimming at four velocities. The results showed a lower IdC with FS (p<.05) and a reduction in PP (p<.01), when taking the mean in speed. The differences in IdC and PP were also significant (p<.01) at the 100-m velocity. The clinical case with an international short-distance swimmer confirmed these results. When wearing a Fastskin suit, the swimmer had fewer constraints, could swim higher on water, and did not need to stack his actions. His coordination at a given speed wearing a Fastskin suit corresponded to the coordination at a slower speed without a Fastskin suit.

Key words: Fastskin suits, buoyancy, glide, coordination, front crawl.

METHODS
The study was composed of two parts. The first part compared the buoyancy, passive torque, glide and arm coordination of 15 swimmers (6 females and 9 males, Table 1), with and without a Fastskin swimsuit. Measurement of anthropometric parameters started the experiment.

The buoyancy test consisted of measuring the hydrostatic lift. The swimmers were asked to perform a forced and complete inspiration and then to float in foetal position. Weights were added on their back until they began to sink slowly. The hydrostatic lift corresponded to the weight needed to maintain the subject just under the water. The passive torque test consisted of measuring the time needed for the subject to turn from horizontal position (lying on the back, arms alongside the body) to vertical position. Subjects were asked to do this test three times, and the mean result was kept. The glide was measured by the distance covered during the swim when pushing from the pool wall (feet to feet). The subjects were asked to glide as long as possible without moving at all after pushing, in the best profile position possible, arms extended ahead of the body. This test was repeated three times, and the mean result was kept.

To analyse coordination, the swimmers were asked to swim 25 m at four different velocities (corresponding to the paces, stroke rate, stroke length and breathing of 1500-, 400-, 100- and 50-m) with and without the swimsuits they usually use in competition. Two underwater video cameras with rapid shutter speed (1/1000 s) were used at the rate of 50 images per second. Each camera was fixed on a trolley, which ran along the side of the pool to ensure filming of the swimmers. One camera filmed the swimmer from an aerial side view, the other from an underwater side view. An operator at the same velocity as the swimmers pulled the trolleys. The cameras were connected to a double-entry audio-visual mixer, a video recorder and a monitoring screen to mix the two lateral views on the same screen, in accordance with the protocol of Chollet et al. (2000). A video timer was incurred in the mixer to synchronize the two lateral views. A third camera, mixed with the underwater side view for time synchronization, filmed the underwater frontal view. To analyse the swimmer’s coordination, we use the index of coordination (IdC), which enables to identify three modes of coordination as regards the degree of continuity between the propulsive actions. The IdC calculation is based on the time gap existing between the start of propulsion of one arm and the end of propulsion of the other arm.

The aim of our study was to compare the effect of Fastskin swimsuits on lonomy, glide efficiency and IdC in front crawl swimming.

Table 1. Population’s characteristics

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Size (cm)</th>
<th>Weight (Kg)</th>
<th>%World Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (9)</td>
<td>25.88 ± 4.9</td>
<td>186.44 ± 2.9</td>
<td>80.44 ± 7.5</td>
</tr>
<tr>
<td>Female (6)</td>
<td>22.5 ± 5.3</td>
<td>167.5 ± 2.06</td>
<td>56.5 ± 1.5</td>
</tr>
</tbody>
</table>

The main results showed that IdC increases with velocity. In other words, swimmers tend to increase the duration of the propulsive phases when they increase velocity. This index was notably used to compare the arm coordination in front crawl between elite triathletes and swimmers (Millet et al., 2002).
with a standard suit (SS). The statistical analysis was performed using Student t tests.

The second part was a clinical case study. The subject was an international swimmer, a member of the French national swim team for many years (31 years old, 190cm, 89kg), and was a specialist of short distances in front crawl swimming (93.93% WR on the 50-m event, and 93.98% WR on the 100-m event). This swimmer performed the whole experiment four times: in a standard suit, in an Arena Extrem® suit, in an Arena Powerskin-Revolution® suit and in a Speedo LZR® suit.

RESULTS
The results of the first part of this study showed no significant differences in buoyancy, glide or passive torque. A significant decrease in IdC (Fig. 1a) and the percentage of propulsive phase of the stroke (Fig. 1b) was detected by looking at the average values (without taking into account the velocities).

Further analysis of the data showed that that the IdC (Fig. 2) and percentage of propulsive phase did not change significantly for the 1500-, 400- and 50-m velocities, but both were significantly different at the 100-m velocity.

In the second (clinical) part of this study, the results showed some substantial differences between the effects of the Fastskin suits.

A first general analysis showed significant differences with and without a Fastskin suit for this swimmer, for both the average IdC (Fig. 3a) and the average percentage of propulsive phase (Fig. 3b). The results showed no other significant differences with and without a Fastskin suit.

DISCUSSION
The first part of the study included six females and nine males and the performance constraints in swimming are specific. However, the results concerned mainly the effect of Fastskin suits on coordination and thus were based on the averages across gender and, for the first step, swim velocities.

The subjects swam at increasing swim speeds (from low to high speeds) with and without Fastskin suits. In accordance with the instructions, speeds, stroke rates and stroke lengths were similar (respectively: 1.593 ± 1.599 m·s⁻¹, 38.54 vs. 38.70 cycles.min⁻¹ and 2.55 vs. 2.56 m.cycles⁻¹).

When globally measured, IdC was significantly lower with Fastskin suits than without (-9.56±5.9 vs. -8.32±6.8, e.g., Fig. 1a). The IdC is dependent on individual and environmental constraints (Seifert et al., 2007), and wearing a Fastskin suit lowered resistance to forward movement, which in turn resulted in more efficient propulsive actions for the same given speed. Indeed, the Fastskin suit significantly affected the values for the propulsive phases: glide phases increased and consequently propulsive phases were reduced (40.29±5.6 vs. 41.6±16.8 %).

Examination of the specific effects of the speed increases showed that IdC increased when speed increased, in accordance with previous studies. The reduction in IdC with the Fastskin suits was significant for the global analysis but closer examination revealed that this was only significant for the 100-m velocity (Fig. 2). It thus appears that, despite the claims of improved buoyancy, the effects of these new generation suits are greater for high rather than low velocities. One interpretation is that the compressive effect of these new suits, by reducing body volume and thus damaging buoyancy, is offset by an improvement of the Cx due to this compression. The effects measured in the older generation suits, which were more useful for long distances and triathlons (Chatard et al., 1995; Hue et al., 2003; Toussaint et al., 2002), no longer hold for this newest generation. The compression of body volume is thus more useful for high speeds than for slower speeds. The observation of a non-significant difference at the 50-m pace can be interpreted as a reflection of the population profile: none of the swimmers was a sprint specialist.

The case study of a real sprinter (World Championship medallist for the relay and individuals) enabled us to refine our conclusions concerning high speed and also to compare several new generation Fastskin suits on the same subject. It appeared that, according to the instructions, swim speeds were similar with and without Fastskin suits. However, stroke rate and stroke length were affected (for the same velocity) by the SLZR.

In accordance with IdC logic, the swimmer turned significantly to catch-up coordination when wearing the Fastskin suits, since he used superposition coordination without Fastskin suits (-3.31±4.04 vs. 1.45±2.68). This case confirmed the change in coordination logic seen with the global population, and also confirmed that, thanks to a
Fastskin suit, a real sprinter does not have to stack his action to reach his highest speed. Similar to the findings in the global population, the propulsive phases were significantly reduced when wearing a Fastskin suit (46.40±4.03 vs. 51.26±3.88%). Moreover, the SLZR had a specific influence on the stroke length/stroke rate ratio and also on coordination and the propulsive phases. In fact, it appeared that the effect of wearing this suit was the opposite of the effects of the two other Fastskins. It thus seems that the morphological characteristics of the swimmer and the technical characteristics of the swimsuit have combined and specific effects. Passive torque measurement also indicated these differences. Each swimmer being unique, the same swimsuit could have a different effect for another swimmer. This case study also showed that the same swimmer wearing different swimsuits was affected differently.

CONCLUSION
The new generation Fastskin suit, which does not improve buoyancy, had the effect of improving glide and reducing drag. Because of these effects, swimmers have fewer constraints, can therefore swim higher in the water, and do not need to stack their actions. Coordination when wearing a Fastskin suit corresponds at a given speed to coordination at a slower speed without a Fastskin suit.

REFERENCES

The Effect of Wearing a Synthetic Rubber Suit on Hydrostatic Lift and Lung Volume

Buoyancy improvement is the result of the use of a technical suit to increase swimming speed. Hydrostatic lift and lung volumes were measured in 9 competitive swimmers while wearing a “standard” swimsuit (S) or a full body synthetic rubber suit (Xg). The average values of the hydrostatic lift were 14.51 ± 4.53 N with S and 14.33 ± 3.99 N with Xg. The average values of lung volumes when wearing S and Xg were VC 6.31/6.14 L, ERV 2.12/1.79 L, VT’ 0.94/0.88 L, IRV 3.26/3.47 L, respectively. A strong thoracic and/or abdominal compression caused by the technical suits may be related to the observed reduction in the chest and abdominal circumstances during maximal inspiration and expiration, as well as to the reduction in the lung volumes and in the hydrostatic lift. The improvement in performance obtained by wearing Xg is not related to better static buoyancy.

KEYWORDS: hydrostatic lift, buoyancy, bodysuit, swimming, lung volume

INTRODUCTION
In the last World Championships, held in Rome in 2009, swimmers utilized suits produced partially or entirely with industrial polymers and 43 world records were broken. Even if the effect of these technical suits in determining the increase in swimming speed is still not fully understood, their advantage may be related to the increase of buoyancy. Benjanuvatra et al. (2002) did not find any improvement in buoyancy when wearing technical (cloth) suits. However, according to Technical Commission of F.I.N.A., the possible air-trapping effect, i.e. “air sacks” between the suit and the swimmers body, has to be taken into account for suits entirely made in polyurethane/neoprene. Indeed, the hydrostatic weight of these suits should be less than 1 N according to F.I.N.A. rules (Dubai Charter on F.I.N.A. requirements for swimwear approval 2009).

The aim of this work was to evaluate the differences in hydrostatic lift in swimmers wearing (or not wearing) a suit made of polyurethane/neoprene and to relate these findings with possible variations in lung volume.

METHODS
Nine male swimmers (23.25 ± 3.01 years of age; 1.80 ± 0.03 m of stature; 75.45 ± 6.96 kg of body mass) were asked to perform two different tests. In the first test their hydrostatic lift was measured in a swimming pool (water temperature: 27.5°C) while wearing a “standard” textile brief swimming–suit (S) or a full body shoulder-to-ankle technical suit (X-glide Power-skin Arena Italy, not modified: Xg). Before the measurements the subjects were asked to warm-up for about 10 minutes. After the warm-up, the subject wore the swimming suit required for the test. Particular attention was paid to reproduce the pre-race situation asking the subjects not to perform any “not conventional” manoeuvre of “adaptation” of the swimsuit. After the warm up phase, the subjects were kept for 10 s under the water surface. They were held in position throughout a cable, connected to a pulley system positioned on the swimming pool floor and fastened to the subject waist (Figure 1). The cable was also connected to a load cell (Tesys 400, Globus, Italy) positioned on the pool’s edge that allowed to measure the subject’s hydrostatic lift (the force with which their body tended to rise towards the water surface). Ten measurements were collected in both conditions (with S and Xg swimming suits). During these tests the subjects were required to hold their breath after a forced maximum inspiration and not to exhale for the entire duration of the test.
The second test was carried out in the laboratory: chest circumferences and 14.33

In this case the subject is wearing a "standard" swimming suit. Despite the fact that mean differences were

small but significant buoyancy for standard swimming suits compared to 50% polyurethane (Fast-skin, Speedo) swimming suits. Cordain and Kopriva (1991) also suggested that an increase in buoyancy obtained by wearing the Xg suit.

The intra-class correlation coefficient (ICC) computed for the 10 trials (R = 0.94, p<0.05) showed good reliability of measurements. Therefore, the mean of all trials was considered for further analysis. A significant difference was observed (p<0.05) even if the difference between the two sets of data was rather small (average difference in force was 0.18 ± 1.63 N only).

The average (+1SD) values of the chest circumference during maximal expiration (R=0.86) were 88.6 ± 3.70 cm for S and 86.6 ± 3.39 cm for Xg, whereas during maximal inspiration (R=0.99) was 97.3 ± 3.26 for S and 95.6 ± 2.48 for Xg. None-significant statistical differences (p>0.05) were observed in both cases.

The average (+1SD) values of the lung volumes investigated in this study are also reported in Table 1. Statistical differences were observed in all cases but not for the tidal volume (TV). These data indicate a general decrease in lung volumes and chest circumferences when wearing a technical suit and this suggests that these swimming suits generate compression of the chest and/or abdomen. This would justify the fact that by wearing a technical swimming suits subjects are less buoyant than when wearing a standard swimming suits (see above) even if the former is expected to increase buoyancy of a least 1 N.

Table 1. Average (+1SD) values of lung volumes (in l) while wearing a standard swimming suit (S) and a technical suit (Xg).

<table>
<thead>
<tr>
<th></th>
<th>Xg</th>
<th>S</th>
<th>Xg-S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERV</td>
<td>1.79 ± 0.45</td>
<td>2.12 ± 0.47</td>
<td>-15.5%</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>VT</td>
<td>0.88 ± 0.17</td>
<td>0.94 ± 0.19</td>
<td>-6.3%</td>
<td>NS</td>
</tr>
<tr>
<td>IRV</td>
<td>3.47 ± 0.48</td>
<td>3.26 ± 0.44</td>
<td>6.5%</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>VC</td>
<td>6.14 ± 0.79</td>
<td>6.31 ± 0.72</td>
<td>-2.8%</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

DISCUSSION

In the literature, there is no general agreement on the reason why there might exist an advantage in using technical suits, even if the improvements in performance promised by the producers are unquestionable. Furthermore, no studies have been focussing on the effect of synthetic rubber technical suits in swimming. Some authors, measuring active or passive drag with and without textile full-body suits, suggested that their use could determine a more or less consistent advantage and attributed these differences to a drag reduction (Toussaint et al. 2002, Pendergast et al. 2006). Of the three main components of total drag (pressure, wave and friction), friction seems to be largely influenced by these suits. However, as indicated by Mollendorf et al. (2004) and Blixer et al. (2007) friction drag represents only 10-15 % of total drag. Hence, the reduction of this component alone is probably not sufficient enough to justify the large differences in performance that the use of these suits brings about.

According to other authors, static buoyancy could be a factor influencing performance (McLean and Hinrichs, 2000) and it seems possible that the new kind of suits can influence this parameter. Indeed, F.I.N.A.‘s Technical Commission pointed out that there could be an effect of air-trapping caused by air that remains imprisoned between the suit and the swimmers’ body. The hydrostatic weight of these suits should be less than 1 N according to F.I.N.A. rules (Dubai Charter on F.I.N.A. requirements for swimwear approval 2009).

Different studies have been carried out to evaluate the hydrostatic lift differences while wearing different kinds of swimming suits in different modalities (Yamamoto, 1999, Benjanuvatra 2002, Tomikawa 2003, Roberts 2003, Perrier 2002, Perrier, 2004, Tomikawa 2009, Ch tard 2008); however, some of them were triathlon swimming suits, particularly thick and not used in competitive swimming races.

As far as “proper” swimming suits are concerned no differences in hydrostatic lift were observed by some authors (Benjanuvatra et al. 2002, Ch tard and Wilson 2008) whereas others (Roberts et al. 2003) found small but significant buoyancy for standard swimming suits compared to 30% polyurethane (Fast-skin, Speedo) swimming suits. Cordain and Kopriva (1991) also suggested that an increase in buoyancy obtained artificially could give a bad influence to the technical performance.

CONCLUSION

In this study, average hydrostatic lift was found to be smaller (albeit the difference was rather small) when the subjects were wearing a technical swimming suit. This finding could be related to the observed reduction in the chest and abdominal circumferences during maximal inspiration and expiration, as well as, to the reduction in lung volume. In turn, these findings could be attributed to a strong thoracic and/or abdominal compression caused by the technical suits. It must be noted that the data reported in this study indicated an effect of these suits that is opposite to the “air-trapping effect hypothesis”. In conclusion, according to the data presented here, the improvement in performance obtained by wearing Xg is not related with better static buoyancy, even if these technical suits make indeed the difference in dynamic conditions.

Figure 1. The set up utilized for measuring the subject’s hydrostatic weight. In this case the subject is wearing a "standard" swimming suit.

The subjects were wearing the S or Xg suits. Lung volumes (VC: Vital Capacity, ERV: Expiratory Reserve Volume, VT: Tidal Volume, IRV: Inspiratory Reserve Volume) in the two conditions were measured (Standard Lung Function Test) by means of a portable spirometer (K4 Cosmed, Italy). These tests were carried out according to standard technical procedures (Guidelines for lung function test 1994). The subjects were first familiarized with the procedures; they were asked to repeat these measurements four times, the average value of these measures was utilized for further analysis.

With regard to the statistical analysis, mean and standard deviation (SD) were calculated for all the variables. Test-retest intra-class correlation coefficient (ICC) was calculated to assess the reliability of the hydrostatic lift. Non-parametric Wilcoxon test was used to compare differences of hydrostatic lift values in the two conditions of suit. The 95% level of significance was accepted for all comparisons (p<0.05).

RESULTS

The average values (+1SD) of hydrostatic lift were 14.51 ± 4.53 N for S and 14.33 ± 3.99 N for Xg. Thus, even the suit’s buoyancy (as indicated by the producer) was of 1 N, the hydrostatic lift was smaller with the technical swimming suit. Despite the fact that mean differences were rather small, it appears that no swimmer could profit from the buoyancy advantages wearing the Xg suit.

The intra-class correlation coefficient (ICC) computed for the 10 trials (R = 0.94, p<0.05) showed good reliability of measurements. Therefore, the mean of all trials was considered for further analysis. A significant difference was observed (p<0.05) even if the difference between the two sets of data was rather small (average difference in force was 0.18 ± 1.63 N only).

The average (+1SD) values of the chest circumference during maximal expiration (R=0.86) were 88.6 ± 3.70 cm for S and 86.6 ± 3.39 cm for Xg, whereas during maximal inspiration (R=0.99) was 97.3 ± 3.26 for S and 95.6 ± 2.48 for Xg. None-significant statistical differences (p>0.05) were observed in both cases.

The average (+1SD) values of the lung volumes investigated in this study are also reported in Table 1. Statistical differences were observed in all cases but not for the tidal volume (TV). These data indicate a general decrease in lung volumes and chest circumferences when wearing a technical suit and this suggests that these swimming suits generate compression of the chest and/or abdomen. This would justify the fact that by wearing a technical swimming suits subjects are less buoyant than when wearing a standard swimming suits (see above) even if the former is expected to increase buoyancy of a least 1 N.
REFERENCES


The Development of a Component Based Approach for Swim Start Analysis
Cossor, J.M.¹, Slawson, S.E.², Justham, L.M.², Conway, P.P.², West, A.A.³

¹British Swimming, Loughborough, England
²Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, Loughborough, England

A component-based system was developed to provide greater quantitative feedback of starts based on input from British Swim coaches. Currently the information provided by the system comprises integrated vision, force data from an instrumented starting platform and wireless three-axis acceleration data. Initial testing has demonstrated the reliability of the system and the direct impact of intervention with an elite athlete.

Key words: swimming, starts, vision system, force platform, wireless acceleration

INTRODUCTION
Swimming races are divided into the start, turn, and free swimming sections. The contribution of each phase to overall performance is dependent on race length. The start has a greater contribution to success in the sprint events compared with longer distances. Analysis of female freestyle sprint events at the Beijing Olympics, illustrates that a 1% reduction in start time would be larger than the time difference between the first and second places (Slawson, 2010).

Research on swimming starts has included information on the block, flight, underwater and free swimming phases. Block time has been the most measured parameter although forces and velocities leaving the block are generally discussed in relation to the block phase. Arellano et al. (2005) and Mason et al. (2007) suggested that increased horizontal force results in better starts. Flight time and distance are the main reported parameters associated with the flight phase although the angle of entry has been noted as being important to overall start performance (Ruschel et al., 2007). While it is noted that the underwater phase can be the longest in terms of time, the block and flight phases significantly influence the drag forces experienced by the swimmer in the glide phase (Mason et al., 2007). Transition into the break out and the free swimming sections also contribute to the overall start time and variations between swimmers are usually attributed to differences in underwater kicking skill.

The use of vision systems is still the most common analysis technique but it can be user intensive and costly. Force plate analysis has been successful utilised due to the reliability of the system along with the capability to provide real time measures. To date, the limitation of utilising force data has been in the interpretation of these data and the subsequent development of interventions for improved performance.

Accelerometers have been used in the understanding of human movement and performance in areas such as gait, sleep and healthcare. Research using accelerometers in swimming has included the derivation of information on stroke count, lap count and stroke type (James et al., 2004, Ohji, 2006, and Davey et al., 2008). Acceleration systems can be characterised into either real-time data transmission or logging and download units. Only the latter system has been used in swimming research and only on a one to one basis. Although useful information on free swimming performance has been disseminated from these studies, a wireless networked solution would enable data to be collected real time from a pool of athletes. A system has been designed, implemented and evaluated in the current research that allows many wireless nodes to transmit in real-time to a co-ordinating receiving unit that acts as the interface to visualisation, analysis and storage on conventional personal computers.
This study was used to determine and evaluate the efficacy of performance variables that significantly contribute to the overall starting performance. In addition, in pool testing has demonstrated the reliability of the system and the impact of intervention strategies on the performance of elite athletes.

METHODS
A force platform incorporating four Kistler (9317B) transducers into a starting block with similar dimensions to the Omega OSB9 block has been designed at the Sports Technology Institute at Loughborough University. Three orthogonal axes of force data were synchronised with video output from a Photron SA1 high-speed camera set at 50fps with a resolution of 1024 x 1024 pixels. A wireless accelerometer node was placed at the small of the back of the swimmer in order to gain information on the accelerations generated during the start. A schematic of the testing set up is illustrated in Figure 1.

Figure 1. Set up incorporating a video, force platform and wireless accelerometer node.

A variety of tests were conducted using the instrumented block to capture force data on twenty male and female swimmers ranging from National to International level over a period of twelve months. Tests included swimmers performing a number of trials on one day, the same swimmers repeating trials one month later, as well as some swimmers testing the difference between grab and track starting techniques. An external analogue trigger synchronised the capture of data from the force platform and video camera whilst simultaneously generating an audio signal for the swimmer to start. Various parameters of the block and flight phases of the start were determined from the analysis of the force data and correlated with the images recorded via the vision system. During the block phase the time to first movement, horizontal and vertical forces, and overall block time were determined. Using the moments generated on the force platform, centre of pressure was examined. Flight distance and time to 15m were determined via the vision data whilst flight times, time to the first stroke and number of strokes prior to 15m were determined from accelerometer data generated by the wireless node.

RESULTS
The initial focus of the research was on the validation of the data from the force platform. A number of University swimmers were tested using both grab and track starts. Unfortunately it was noted that this level of swimmer was unable to demonstrate a consistent enough dive force profile to enable performance improvements to be evident between different dives.

Further testing was undertaken with an International level swimmer where a significantly high degree of repeatability was evident in the force profiles (see Figure 2). Very little difference between the timing, amplitude and profile of the individual trials for the elite swimmer were observed compared with the significant variability in these parameters shown for the trials provided by an amateur swimmer as seen in Table 1. There was 0.7% difference in the impulse for the elite swimmer compared to 9.8% for the University swimmer. Likewise there were only 1.2% differences in timing and maximum forces in the horizontal and vertical planes for the elite athlete but 16.3% and 14% differences respectively for the University swimmer. Hence via the detailed examination of the characteristics of starting force profiles over repeated trials it is possible to determine relevant measures of athlete skill level (i.e. variance in timing, impulse, and number of peaks) without the aid of vision systems.

Table 1. Horizontal and vertical force data for different levels of swimmers.

<table>
<thead>
<tr>
<th>Dive</th>
<th>Max y</th>
<th>Time</th>
<th>Max Z</th>
<th>Time</th>
<th>Unload time</th>
<th>Impulse y</th>
<th>Impulse z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>414.72</td>
<td>0.75</td>
<td>725.17</td>
<td>0.73</td>
<td>0.92</td>
<td>151.67</td>
<td>444.28</td>
</tr>
<tr>
<td>2</td>
<td>415.27</td>
<td>0.76</td>
<td>741.22</td>
<td>0.73</td>
<td>0.94</td>
<td>149.59</td>
<td>444.34</td>
</tr>
<tr>
<td>Uni</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>554.17</td>
<td>0.51</td>
<td>929.48</td>
<td>0.64</td>
<td>0.87</td>
<td>181.67</td>
<td>530.17</td>
</tr>
<tr>
<td>2</td>
<td>454.62</td>
<td>0.70</td>
<td>857.96</td>
<td>0.70</td>
<td>0.94</td>
<td>159.31</td>
<td>565.67</td>
</tr>
</tbody>
</table>

An intervention was designed for the International level swimmer in order to improve their starting performance. The force profiles for the new dive technique in both the horizontal and vertical components are illustrated in Figure 2. The standard dive technique profiles are provided for comparison. With the new dive technique, the timing of the first movement was observed to be earlier (0.1s) with the same peak force in the horizontal direction while there was a 6% reduction in peak vertical force compared to the traditional start. This type of quantitative feedback on measures of performance highlight the benefits of a system that is not labour or time intensive and allows for immediate feedback so that changes in technique can be observed.

Figure 2. Comparison of force data an elite swimmer using different techniques.
In Figure 3 an example of the information provided to the coach and swimmer is illustrated. From the force data it is possible to determine the block time, the time of first movement, peak horizontal and vertical forces as well as centre of pressure information. The vision system information is used to provide information relevant to the flight phase of the start i.e. the flight distance and flight time. The timing of the first stroke as well as the number of strokes through to the 15 m mark can be determined using the acceleration data. The inclusion of the vision data in the report provides a detailed initial understanding of the force data collected during the block and flight phases.

![Image of Figure 3](image.png)

Figure 3. Track start analysis combining vision systems, force profiles and acceleration data.

**DISCUSSION**

Individual monitoring components have been developed that enable parameters relevant to the performance of various components of the start phase of swimming to be quantified. The three main monitoring components include vision information, force profiles and acceleration data through a network of distributed wireless nodes. Each of these components is able to provide feedback to the coaches and the athletes but it is the synchronisation and integration that allows a greater level of understanding to be obtained.

From the video images it is possible to provide qualitative feedback immediately after each start. By synchronising this with the force platform information, quantitative values during the block phase can be calculated and fed back to the coaches and swimmers. An example of this integrated analysis approach was shown with the elite level athlete whilst undergoing an intervention in their starting technique resulted in quantifiable visible differences in both the horizontal and vertical force components. The addition of wireless acceleration information is unique to this analysis of swimming starts where information on stroking and timing is included in the data analysis.

Results from a number of trials of the integrated system have highlighted the reliability of the data and the impact of interventions. The synchronisation of data from a number of monitoring modalities provides accurate, timely and relevant feedback to both the coaches and athletes supporting enhanced impact from testing. Future work will be focused on the development of a more complete understanding of force and acceleration data and the implications for skill and performance improvement throughout the various phases of the start.

**CONCLUSION**

An integrated component-based system has been developed that allows swimming starts to be analysed in greater detail than possible with previous systems via integrated video, force and acceleration data. Feedback was provided to the coach and athlete for interventions in training to be made and the impacts to be quantified in detail. Future work will examine the impact on starting performance of the wedge included on the next generation Omega OSB11 starting blocks, which are likely to be used in the London 2012 Olympic Games.

**REFERENCES**


Hydrodynamic Characterization of the First and Second Glide Positions of the Underwater Stroke Technique in Breaststroke


1 University of Porto, Faculty of Sport, Cifó2d, Porto, Portugal
2 University of Beira Interior, Covilhã, Portugal
3 Research Center In Sports, Health and Human Development, Vila Real, Portugal
4 University of Trás-os-Montes and Alto Douro, Vila Real, Portugal

The aim of the present study was to characterize two different ventral glide positions, both used after start and turns: the arms extended at the front, and the arms extended along the trunk, respectively the first and the second glide positions of the breaststroke underwater stroke. Inverse Dynamics was used for obtaining the passive drag and the drag coefficient, based upon the velocity to time curve of each glide, monitored through a swim-meter. The first glide position presented lower values of drag and drag coefficient, managing to reach higher velocities. The cross sectional area (planimetry) values were lower for first glide position in comparison with the second one (759.95 ±124.12 cm² vs. 814.46 ±111.23 cm²). These results point out the need of technical evaluation and control in order to reduce drag during swimming performance.

KEY WORDS: swimming, breaststroke, passive drag, drag coefficient, gliding position

INTRODUCTION

In swimming the total event time is determined by the start, swim, turn and finish partial times (Håländ and Saagpakk, 1994). Starts and turns appear to be a significant part of the total swimming event time (Vilas-Boas and Fernandes, 2003). Chatard et al. (1990) stated that the gliding phase after both start and turns corresponds to 10 to 25% of the total event time (depending on events and the length of the swimming pool). D’Acquisto et al. (1988) showed that, during the breaststroke events, the gliding phases represent 44% of the total swimming time. These authors showed that the gliding phase distinguishes elite from good level breaststroke swimmers, with higher gliding time for the elite swimmers. Race analysis suggested that rather than the start technique used by swimmers; it is the position under the water that mostly determines the success of the start (Cosor and Mason, 2001). Therefore, it is essential to analyse and understand this phase. The passive drag of swimmers moving underwater in a streamlined position has been measured experimentally (Clarys, 1979; Kolmogorov et al., 1997; Lyttle et al., 2000; Toussaint et al., 2004; Vilas-Boas et al., in press). However, there are other gliding phases in which the swimmers assume a prone position but with the arms extended at the side of the trunk, as in the second glide position after the breaststroke underwater arm stroke. To our knowledge, these two glide positions were compared experimentally only by Vilas-Boas et al. (in press), and numerically by Marinho et al. (2009). In both cases, the glides were compared in common velocities, not considering the total range of velocities at which they are usually performed. The aim of the present study was to experimentally characterize the first and second gliding positions of the breaststroke underwater stroke used after start and turns at the total range of velocities commonly performed, considering: (i) gliding velocity (v); (ii) body cross sectional area (S); (iii) drag coefficient (C_D); and (iv) passive drag (D).

METHODS

Six Portuguese national level male swimmers (18.2 ± 4.0 years old, 178.2 ± 9.0 cm of height and 64.4 ± 11.4 kg of body mass) participated in this study. Testing sessions were conducted in a 25 m pool, 2 m deep, with water temperature at 27.5 °C. It was used a similar methodology to the described in Vilas-Boas et al. (in press), namely the S determination using planimetry, and the passive drag assessed through inverse dynamics based upon the velocity to time curve (v(t)) curve of each glide, monitored through a swim-meter (Lima et al. 2006). Acceleration (a) was obtained through the numerical derivative of the velocity curve. The drag force was computed using the expression:

\[ D = m \cdot a \]  \hspace{1cm} (1)

To quantify the drag coefficient, the following equation was used, assuming water density (ρ) at 1000 kg/m³:

\[ C_D = 2 \frac{D}{\rho S v^2} \]  \hspace{1cm} (2)

Each swimmer performed 3 repetitions of the breaststroke underwater stroke, at maximal intensity (2 min of interval). During the rest interval, swimmers received proper feedback in order to improve their performance. The video images and data processing (v(t) curves and acceleration to time curves representations) of the first and second glide of the underwater breaststroke were obtained according to Vilas-Boas et al. (in press). Not all swimmers attained all velocity values, being retained the v values (independently in each glide) for which there were values from at least three swimmers. The processes of D and C_D calculations were described also in Vilas-Boas et al. (in press).

RESULTS

The main results of this study are presented in Table 1 and in Figures 1 and 2. Table 1 shows the S values for each swimmer in the first and second glides while Fig. 1 and 2 show D and C_D, respectively, for each glide and for all v values attained.

<table>
<thead>
<tr>
<th>Swimmer</th>
<th>S (cm²) for first glide position</th>
<th>S (cm²) for second glide position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>971.13</td>
<td>942.1</td>
</tr>
<tr>
<td>2</td>
<td>719.73</td>
<td>886.91</td>
</tr>
<tr>
<td>3</td>
<td>641.7</td>
<td>668.47</td>
</tr>
<tr>
<td>4</td>
<td>689.17</td>
<td>769.24</td>
</tr>
<tr>
<td>5</td>
<td>692.6</td>
<td>718.05</td>
</tr>
<tr>
<td>6</td>
<td>845.34</td>
<td>901.99</td>
</tr>
</tbody>
</table>

Mean ± SD 759.95 ±124.12 814.46 ±111.23

The mean ± SD v values for the first and second glide positions were 1.50 ± 0.22 m/s and 1.15 ± 0.24 m/s, respectively. The first glide presented higher values of mean v, while the second gliding was characterized by higher values of acceleration (0.61 ± 0.24 m/s² to 0.66 ± 0.06 m/s² versus 0.40 ± 0.06 m/s² to 0.63 ± 0.16 m/s² for common values of v, second and first glide respectively). The common velocities for the two gliding phases were 1.20, 1.30, 1.40 and 1.50 m/s (Fig. 1 and 2)

![Figure 1. Drag versus velocity curve in two distinct gliding positions: first glide and second glide of the breaststroke underwater stroke](image-url)
DISCUSSION

The relatively low $v$ values found in this study may be explained by the level and age of the swimmers tested, all of national level, not international elite, and mixing junior and senior swimmers. However, the higher $v$ values were obtained during the first glide, probably due to its time proximity to the wall impulse, as well as to the higher hydrodynamics that characterised it.

As expected, in accordance with our previous results (Vilas-Boas, in press), and with the literature using similar methodology (Clarys, 1979), swimmers showed a smaller $S$ area in the first glide position than in the second position. This fact could be explained by the “compressive” effect over the shoulders and chest width produced by the flexed shoulders, which could be one of the main determinant factors associated with a reduced drag in the first glide. It is important to note that the obtained $S$ values may slightly differ from the actual gliding $S$ values, once it is possible that the gliding alignment of the body may differ from the standing position. In fact, we must assume that it is possible that some swimmers may adopt, at least in some instants during the glide, an inclined body position with respect to the gliding direction. Our observation of the recorded video images revealed some inclined gliding directions, with a coaxial and convenient body alignment, but not any inclined body position regarding the direction of motion that would change $S$ values. We are convinced that this approach is also more accurate for $S$ and $C_D$ assessment than calculating active drag $C_Dr$ values using a constant estimation of $S$ based upon body volume powered 2/3 (Kolmogorov & Duplicischeva, 1982).

The $D$ values calculated in this study (Fig. 1) are consistent with previously passive drag values published for competitive swimmers. Clarys (1979) reported $D$ values of about 52 N at 1.3 m/s for male national-level swimmers. Vilas-Boas et al. (in press) found values of 34.66 ± 7.869 N and 42.92 ± 5.658 N, respectively for the first and second studied glide positions, but at lower velocities than the studied in this paper for the first one, and higher for the second one. In the present study, $D$ ranged between 23.35 N and 58.25 N. For both glides the drag increase with velocity (Fig. 1). However the first glide is characterised by drag values lower for all velocities (Fig. 1), probably due to a parallel and concurrent effect of $S$ and $C_Dr$. The increased body length and slenderness associated with the flexed shoulders and extended position of the arms along the longitudinal axis of the body may reduce $C_Dr$, as well as may have an effect upon the reduction of $S$.

For the first glide, the $C_D$ changed from 0.52 at 1.3 m/s to 0.44 at 1.6 m/s. After analysis of Table 2, it is possible to state that $C_D$ decreases with $v$. For the second glide the drag coefficient changed from 0.95 at 0.8 m/s to 0.47 at 1.5 m/s. The inverse relationship between the $C_D$ and $v$ found in the current study seems to correspond to what was observed in other experimental situations (e.g. Lyttle et al., 2000). Moreover, the gliding position with arms extended at the front (first glide) presented lower drag coefficient values (Fig. 2). This body position is accepted by the swimming technical and scientific communities as the most hydrodynamic position, being called streamline position, because it seems to be the one that allows a higher reduction of the negative hydrodynamic effects of the human body morphology: a body with various pressure points due to large changes in its shape. This position seems to smooth the anatomical shape, especially at the head and shoulders, allowing better penetration of the body in the water during the underwater phases in swimming.

In Fig. 2, the $C_D$ for the first glide position presents lower values for the different velocities in study, while the second glide position provides a greater range of values, causing more variability. This finding points out the presumably higher instability of the second gliding position. Being so, attention needs to be paid to its training and competitive execution.

CONCLUSION

The first glide position with arms extended at the front is characterised by lower values of $D$ and $C_D$, despite it is performed at higher velocities. The $C_D$ decreases with velocity, particularly during the second glide. As a practical consequence, swimmers and coaches should stress the need for body position control during its execution, particularly during the more resistive glide (the second one). These results also pointed out the need of technical evaluation, control and advice to allow drag reductions during swimming performance, and not only emphasising propulsion increase possibilities.

REFERENCES


Biomechanical Characterization of the Backstroke Start in Immersed and Emerged Feet Conditions

De Jesus, K. 1, De Jesus, K. 1, Figueiredo, P. 1, Gonçalves, P. 1, Pereira, S.M. 1, 2, Vilas-Boas, J.P. 1, Fernandes, R.J. 1

1University of Porto, Faculty of Sport, Cif2d, Porto, Portugal 2University of the State of Santa Catarina, Florianópolis, Brazil

The aim of this study was to describe and compare two variations of the backstroke start technique, one with the feet parallel completely submerged (BSFI) and the other with the feet parallel, completely above the surface (BSFE). Dual-media video images were recorded using two cameras positioned in the sagittal plane of the movement. Kinetic data were obtained using an underwater force plate. Handgrips were used allowing the same body elevation relative to the water surface. Findings registered greater flight time and water reach of the centre of mass at BSFI. BSFE seems to produce a greater impulse, and time of hands-off, foot take-off and total start. Through segmental coordination analysis it is possible to speculate that the joint extension time duration might be the variable that best characterizes impulsive synergies.

Key words: Swimming, backstroke, starts, kinematics

INTRODUCTION

The start is unanimously accepted as an important element for success in competitive swimming, especially in the short events, representing ~25% of the competition time in the 50 m event (Lyttle and Benjanuvatra, 2004).

Traditionally, comparisons between different starting techniques used for supine swimming events were conducted to find out which one is the best (Vilas-Boas et al., 2003; Welcher et al., 2008), rather than studying how swimming starts should be performed to obtain the optimal mechanical output. Concerning the backstroke swimming start, the number of studies is rather scarce (cf. Hofmann et al., 2006 and Kruger et al., 2006), none of which has yet dealt with the technical adjustments allowed by the new rules endorsed by FINA that authorize the swimmers to position their feet above water level.

Differences in foot position when on the wall - high (above water level) or low (submerged) - may determine the direction of the resultant vector and, therefore, significantly influence starting performance. A higher foot position may produce a more horizontal component of the wall reaction force, while a lower foot position may produce a vector angle with a more pronounced vertical component, increasing the flight time (Van Ingen Schenau, 1989). The present study aimed to describe and compare two backstroke swimming start variations under different constraints determined by the high and low foot position relative to the water surface.

METHODS

Six male high-level swimmers (22.5 ± 2.94 years old, 1.80 ± 0.07 m height, and 76.6 ± 8.94 kg body weight) performed two sets of 4 maximal intensity backstroke starts using the two variations: feet parallel and submerged (BSFI) and feet parallel and above the surface (BSFE). Rest periods of 2 min were respected between each repetition and a 1 h interval was maintained between sets (BSFI and BSFE).

Two-dimensional kinematics in the sagittal plane was implemented using a dual-media camera set-up (Vilas-Boas et al., 1997). Both cameras (DCR-HC42E PAL System and SVHS-JVCCGR-SX1) operated at a frequency of 50 Hz, with 1/250 digital shutter, and were fixed on a special support placed at the lateral wall of the pool (at 2.50 m from the edge of the pool deck). One camera was placed 30 cm above the water surface, and the other one was placed at a depth of 30 cm below the surface camera (in an IKELITE waterproof box). Cameras were placed at 6.78 m from the plane of movement, synchronized in real time, calibrated with a 2.1 m x 3 m structure, and edited and mixed on a mixing table (Panasonic digital mixer WJ-AVE55 VHS) that exported the final image to a VTR. Images were digitized for kinematic analysis using the Atrial Performance Analysis System (APAS). The anthropometric biomechanical model used was the one proposed by de Leva (1996) using 13 anatomical points.

Kinetic assessment was conducted through an underwater extensometric platform (Roesler, 1997) mounted on a support fixed to the pool wall, measuring at 1000 Hz sampling rate. The handgrip system was adapted to comply with the swimming rules and to allow the same elevation of the body relative to the water surface. Starting signals conformed to the FIN swimming rules using a starter device (ProStart, Colorado, USA). This device was programmed and instrumented to simultaneously produce the start sound, export a LED signal to the video system, and a trigger signal to the Analogical/Digital converter (Biopac, 16 bit).

The backstroke start was divided into three phases (adapted from Hofmann et al., 2006): (i) hands-off (HO), from the start signal to the instant the hands lose contact with the handgrip; (ii) take-off (TO), from the hands-off to the instant the feet leave the force plate and (iii) flight (FL), between the instant the feet leave the force plate until the first water touch. These time reference points were selected according to the characteristic of each velocity-time curve in each movement phase. Several linear kinematic, temporal and kinetic parameters were determined. Temporal variables were: start time (ST) - from the start signal to the first water touch; hands-off time (HOT); take-off (TOT), and flight time (FLT). Kinematical variables were: CM horizontal and vertical position at the starting signal (X0 and Y0), respectively and at water touch (X1 and Y1), and CM horizontal and vertical displacement (Dx and Dy, respectively) during HO, TO and FL phases. The kinetic variable selected was the horizontal impulse (HI, the product of the horizontal component of the wall reaction force times the impulse time duration). Angular kinematical variables were the variation with time of the angular position of the hip, knee and ankle (joint angles), and their first derivative (angular velocity of each referred joint) were also studied. The phase's duration were normalized for the ST.

Descriptive statistics and paired samples Student's tests were used (normality verified by the Kolmogorov-Smirnov test). Significance level was established at 95% (p<0.05).

RESULTS

Table 1 presents mean ± SD values of the 15 linear biomechanical parameters studied in the BSFI and BSFE conditions. It can be noticed that the two backstroke start variations were different in the following temporal variables: (i) a higher FLT for BSFI than BSFE and (ii) higher ST, HOT and TOT for BSFI than BSFE X0, X1, DcCM-HO and DcCM-TO were higher for BSFI than BSFE. The BSFI was also the start variant that implied a lower DcCM-TO, and DcCM-FL. HI was higher for BSFE than BSFI.

Time from start to water touch (ST), time from start to hands off (HOT), time from hands-off to take-off (TOT), time from take-off to water touch (FT), CM horizontal and vertical position at start signal (X0 and Y0) and the water touch (X1 and Y1), respectively, CM horizontal (DcCM-HO) and vertical (DcCM-HO) displacement at hands-off, CM horizontal (DcCM-TO) and vertical (DcCM-TO) displacement at take-off, CM horizontal (DcCM-FL) and vertical (DcCM-FL) and resultant displacement at flight, horizontal impulse at take-off (HI). Significant differences (p<0.05).

Figure 1 displays the mean angular kinematics (angular position and angular velocity) of the hip, knee and ankle during the BSFI and BSFE performance. BSFI registered a higher knee angular displacement at HO (Fig. 1C). Also the knee angular velocity was higher for BSFI, and
Table 1. Mean ± SD values of the 15 linear biomechanical parameters studied for backstroke start variants with feet immersed and emerged (BSFI and BSFE, respectively).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BSFI</th>
<th>BSFE</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST (s) *</td>
<td>0.93 ± 0.08</td>
<td>0.98 ± 0.11</td>
<td>0.01</td>
</tr>
<tr>
<td>HOT (s) *</td>
<td>0.55 ± 0.04</td>
<td>0.59 ± 0.08</td>
<td>0.03</td>
</tr>
<tr>
<td>TOT (s) *</td>
<td>0.23 ± 0.05</td>
<td>0.27 ± 0.04</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>FLT (s) *</td>
<td>0.18 ± 0.09</td>
<td>0.16 ± 0.08</td>
<td>0.01</td>
</tr>
<tr>
<td>XO (m) *</td>
<td>0.53 ± 0.11</td>
<td>0.39 ± 0.07</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>YO (m)</td>
<td>0.09 ± 0.05</td>
<td>0.13 ± 0.11</td>
<td>0.13</td>
</tr>
<tr>
<td>XI(m) *</td>
<td>1.75 ± 0.18</td>
<td>1.58 ± 0.22</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Y1 (m)</td>
<td>0.18 ± 0.10</td>
<td>0.20 ± 0.12</td>
<td>0.21</td>
</tr>
<tr>
<td>DxCM-HO (m) *</td>
<td>0.14 ± 0.06</td>
<td>0.10 ± 0.05</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>DyCM-HO (m)</td>
<td>0.11 ± 0.05</td>
<td>0.16 ± 0.11</td>
<td>0.07</td>
</tr>
<tr>
<td>DxCM-TO (m) *</td>
<td>0.54 ± 0.16</td>
<td>0.63 ± 0.10</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>DyCM-TO (m) *</td>
<td>0.05 ± 0.05</td>
<td>-0.01 ± 0.08</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>DxCM-FL (m)</td>
<td>0.54 ± 0.24</td>
<td>0.50 ± 0.29</td>
<td>0.10</td>
</tr>
<tr>
<td>DyCM-FL (m) *</td>
<td>-0.08 ± 0.08</td>
<td>-0.11 ± 0.09</td>
<td>0.03</td>
</tr>
<tr>
<td>HI (s) *</td>
<td>0.54 ± 0.04</td>
<td>0.71 ± 0.05</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

was achieved at the beginning of the TO (Fig. 1D); the opposite was observed for the ankle joint angular velocity at the beginning of the FLT (Fig. 1F). The timing of BSFE hip joint extension was observed earlier relatively to BSFI, and occurred at ~34% of the HO (Fig. 1B). Meanwhile, the timing of knee and ankle joint extension during BSFE were observed to be later than those obtained for the BSFI, occurring at ~62% of the TO (Fig. 1D) and ~76% of the FLT (Fig. 1F), respectively. Despite the temporal differences between the backstroke start variants, the kinematic analysis suggests the existence of hip-knee-ankle joint sequence.

![Figure 1](image-url)
DISCUSSION
The results showed that a higher foot position of BSFE produces a higher horizontal wall approximation of the CM in the starting position. In the same way, BSFE presented a higher HOT. Differences may certainly be attributed to the foot segment constraint in the starting position, which seems to imply a more complex lower and upper limb movement sequence to release handgrip contact at BSFE. Previous values published without these constraints presented values between 0.42 and 0.52 s (Kruger et al., 2006). Differences may be attributed to the higher competitive level of the swimmers of the referred study. In accordance with the analysing movements reported in previous studies such as vertical, horizontal, drop or rebound jumps (Bobbert and Van Ingen Schenau, 1988; Rodacki and Fowler, 2001), during the backstroke start (both variants), the CM is initially accelerated by the extension of the hip joint, although BSFE registered lower time to reach joint peak angular velocity. We can speculate that the more tucked position of the BSFE may imply a higher pre-stretching of the subsequent propulsive muscles. In this situation, the force production capacity of these muscles can be maximized if the time between the stretch and shortening actions, and their loading characteristics respect particular limits. This has yet, however, to be verified.

At BSFI condition a higher knee joint angular displacement was observed, which seems to contribute to a higher $D_{xCM-HO}$. The present results confirmed the hypothesis that the BSFI start condition might result in a different resultant vector angle with a more pronounced vertical component as noted by the higher $D_{yCM-TO}$. As Counsilman (1971) previously stated, few swimmers can perform successfully the BSFE due to the longer training required to increase the vertical component at the instant of take-off. Temporal analysis also revealed that BSFE obtained higher TOT. It may be due to the specific placement of the feet above water level, which seems to imply that the body mass was accelerated through a greater distance after the start signal until the take-off, which explains the higher impulse.

The analysis of segmental co-ordination indicated that BSFI showed greater angular velocity of the knee joint at the beginning of the take-off phase; while, the BSFE condition presented a greater time of knee joint maximal extension. Additionally, BSFI imposed a lower time to reach ankle joint maximal extension, at the end of TO phase.

The paired sample T-test revealed higher FLT and X1 for the BSFI. In a previous study, Miller et al. (1984) found values of 0.11 ± 0.06 s (100 m events) and 0.11 ± 0.05 s (200 m events) for FLT during the backstroke start without foot position specified (but assumed to be BSFI), values that suggested being lower than those found in our study for both variants. Additionally, these authors found similar values to ours for X1, 2.77 ± 0.12 m (100 m) and 2.78 ± 0.12 m (200 m). Nevertheless, differences may be attributed to the end point measurement of the flight analysis, which was established by Miller et al. (1984) as distance to the hand contact with the water instead of the distance to the CM at the hand touch.

CONCLUSIONS
As a performance parameter, the total time spent during the start was lower for BSFI than BSFE, allowing the conclusion that the first, being faster than the second should be preferred for competitive use. This observed superiority of the BSFI may be at least partially justified by the higher flight time (FLT) and reach of the centre of mass (X1). These findings seem to confirm the hypothesis that a lower foot position can determine the CM water reach by constraining the orientation of the resultant wall reaction vector. Inter-segmental coordinate analysis of the lower limbs showed that the relative time at which the knee and ankle peak joint angular velocity occurs might be an important variable to characterize the co-ordination pattern, and to explain the performance capacity of the BSFI. It is recommended that coaches begin monitoring the backstroke start variation strategies to improve inter-segmental coordination, which can be the determining factor of success of the start.

REFERENCES
Tethered Force Production in Standard and Contra-standard Sculling in Synchronized Swimming

Diogo, V. 1, Soares, S. 1, Tourino, C. 1, Abraldes, J.A. 1, Ferragut, C. 1, Morouço, P. 1, Figueiredo, P. 1, Vilas-Boas, J.P. 1, Fernandes, R.J. 1

1 University of Porto, Faculty of Sport, Cisf2d, Porto, Portugal
2 University of Vigo, Faculty of Education and Sport Sciences, Spain
3 University of Murcia, Faculty of Sports Sciences, Murcia, Spain
4 Catholic University of Murcia, Faculty of Sports Sciences, Murcia, Spain
5 Polytechnic Institute of Leiria, CINMH, Portugal

Studies carried out in synchronized swimming are scarce, inclusively with respect to the biomechanical analysis of sculling. The purpose of this study was to measure the force produced in standard and contra-standard sculling, using a 30 s maximal tethered synchronized swimming test. 13 synchronized swimmers performed a 2x30 s maximum intensity tethered synchronized swimming test, in standard and contra-standard sculling conditions, respectively. The variables were: absolute and relative maximal force, the time when maximal force occurred, the mean force, the mean values of maximal and minimal force, and the fatigue index. Results showed that higher values of maximal force were found in the standard sculling. The Fatigue Index evidenced that the maximal force declined with time in all participants and in both sculling conditions.

Key words: biomechanics, sculling, synchronized swimming, tethered swimming

INTRODUCTION

Synchronized swimming is a technical and physically demanding sport, in which the strength and the velocity of movements are combined with high flexibility requirements (Chu, 1999). In this sport, sculling is an often-used technique, consisting in underwater arm stroke patterns whose purpose is the production of hydrodynamic force. This force will allow support, balance and propulsion of the swimmer’s body (Chu, 1999).

Although the importance of sculling in synchronized swimming is undeniable, very few studies were conducted, and none seem to have quantified the force produced by the swimmer. The appearance of fatigue during sculling was also not yet studied. Knowing that there is a high relationship between strength and performance in swimming (Risch and Castro, 2007), and that strength training (with emphasis on neural adaptations) explains, in part, the specific positive changes in velocity and aerobic performance due to a better economy of movement (Hoff et al., 2002), the purpose of this study was to measure the force and the fatigue produced in standard and contra-standard sculling in synchronized swimming, using a 30 s maximal tethered test.

METHODS

Thirteen synchronized swimmers with the same performance level volunteered to participate in this study. Mean (± SD) physical characteristics of the sample were: age 15.8 (2.1) years; body weight 50.5 (8.2) Kg; height 160.9 (7.4) cm; arm span 161.2 (9.7) cm.

A 30 s tethered sculling protocol was used in order to determine individual force to time - F(t) - curves in two conditions: (i) standard sculling (movement towards the head, with the body placed in supine position, the arms in the lateral of the trunk, the wrist in dorsal flexion and the hand palm oriented toward the feet) and (ii) contra-standard sculling (movement towards the feet with the body in supine position, the arms in the lateral of the trunk, the wrist in palmar flexion and the hand palm oriented towards the head). After familiarization with the equipment and a standardized warm-up, each subject performed a 30 s maximum intensity tethered synchronized swimming test. Individual $F(t)$ curves were obtained with the subjects attached by a non-elastic cable to a strain-gauge system (Globus, Italy). The beginning and the end of the test were established through an acoustical signal produced by a researcher. Tests were conducted in an indoor, heated (27.5°C), and 2 m deep swimming-pool.

The absolute and relative maximal forces (Fmax and RFmax, being RFmax = Force.body weight $^{-1}$), the time at which Fmax occurred (FmaxTime), the mean force (Fmean), the average of Fmax (FmaxAvg = average of all force values in the first 5 s of the test), the average of minimal force (FminAvg = average of all force values in the last 5 s of the test) and the fatigue index (FI (%) = ((FmaxAvg-FminAvg)/Fmax-Avg)100) were computed. The force values of the first 2 s test were eliminated in order to remove the high inertial values associated with the first pull (Fig. 1).

After the normality of the distributions was confirmed (Kolmogorov-Smirnov test), T-Test for repeated measures was used to compare mean values of each variable obtained for standard and contra standard sculling techniques. Pearson product-moment correlation coefficient was also computed for the study of relevant association of variables. Significance level was established at 95% (p<0.05).

RESULTS

Absolute and relative values of Fmax, FmaxTime, Fmean, FmaxAvg, FminAvg and the FI are presented in Tables 2 and 3 for standard and contra-standard sculling.

Table 1. Individual and Mean ± SD values of absolute maximal (Fmax) and relative (Relative Fmax) force, the time when the Fmax occurred (FmaxTime), mean force (Fmean), the average of maximal and minimal forces (FmaxAvg and FminAvg, respectively) and the fatigue index (FI) in standard sculling (n=13).

<table>
<thead>
<tr>
<th>Swimmer</th>
<th>Fmax (N)</th>
<th>Relative Fmax (N/kg)</th>
<th>FmaxTime (s)</th>
<th>Fmean (N)</th>
<th>FmaxAvg (N)</th>
<th>FminAvg (N)</th>
<th>FI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>30.8</td>
<td>0.60</td>
<td>4.9</td>
<td>12.9</td>
<td>8.7</td>
<td>15.8</td>
<td>44.7</td>
</tr>
<tr>
<td>#2</td>
<td>42.9</td>
<td>0.82</td>
<td>7.0</td>
<td>22.1</td>
<td>19.8</td>
<td>25.5</td>
<td>22.3</td>
</tr>
<tr>
<td>#3</td>
<td>36.1</td>
<td>0.63</td>
<td>2.7</td>
<td>21.5</td>
<td>16.4</td>
<td>26.5</td>
<td>38.3</td>
</tr>
<tr>
<td>#4</td>
<td>18.6</td>
<td>0.42</td>
<td>2.6</td>
<td>5.6</td>
<td>3.9</td>
<td>10.3</td>
<td>61.8</td>
</tr>
<tr>
<td>#5</td>
<td>33.3</td>
<td>0.74</td>
<td>8.6</td>
<td>14.0</td>
<td>9.2</td>
<td>20.6</td>
<td>53.4</td>
</tr>
<tr>
<td>#6</td>
<td>50.1</td>
<td>1.13</td>
<td>4.2</td>
<td>24.8</td>
<td>20.4</td>
<td>32.5</td>
<td>37.2</td>
</tr>
<tr>
<td>#7</td>
<td>51.9</td>
<td>0.83</td>
<td>7.9</td>
<td>26.8</td>
<td>24.7</td>
<td>29.9</td>
<td>17.5</td>
</tr>
<tr>
<td>#8</td>
<td>23.9</td>
<td>0.72</td>
<td>6.7</td>
<td>7.0</td>
<td>4.7</td>
<td>10.6</td>
<td>55.8</td>
</tr>
<tr>
<td>#9</td>
<td>39.7</td>
<td>0.87</td>
<td>5.5</td>
<td>14.1</td>
<td>8.2</td>
<td>18.9</td>
<td>56.9</td>
</tr>
<tr>
<td>#10</td>
<td>39.0</td>
<td>0.74</td>
<td>2.5</td>
<td>20.1</td>
<td>14.4</td>
<td>26.0</td>
<td>45.2</td>
</tr>
<tr>
<td>#11</td>
<td>62.6</td>
<td>0.99</td>
<td>4.3</td>
<td>14.0</td>
<td>5.8</td>
<td>26.4</td>
<td>78.1</td>
</tr>
<tr>
<td>#12</td>
<td>49.4</td>
<td>0.90</td>
<td>3.4</td>
<td>9.8</td>
<td>4.9</td>
<td>14.7</td>
<td>66.8</td>
</tr>
<tr>
<td>#13</td>
<td>51.9</td>
<td>1.04</td>
<td>8.2</td>
<td>24.0</td>
<td>20.6</td>
<td>30.1</td>
<td>31.6</td>
</tr>
</tbody>
</table>

For almost all the subjects, higher absolute and relative Fmax values were found in standard sculling (Table 1 and 2). Mean differences were statistically significant for both values. The values of FI evidence that the FI, despite all the fluctuations observed (see an example in Fig. 1), decreased during the 30 s effort in all participants and in both sculling conditions. With the exception of Fmax absolute and relative values, none of the remaining variables showed statistical significant differences between standard and contra-standard sculling actions.

The correlation study demonstrated the following findings: (i) age correlated significantly with Fmax (r=0.77), with Fmean (r=0.66), and with FmaxAvg (r=0.71), but only for the contra-standard action; (ii) body mass correlated significantly with Fmax (r=0.66 and r=0.76) and with FmaxAvg (r=0.51 and r=0.66), respectively, for the standard and contra-standard sculling; (iii) body height only correlated with Fmax (r=0.54) for the standard sculling; (iv) arm span correlated significantly with Fmax for both sculling actions (r=0.73 for the standard and r=0.63 for the contra-standard) and (v) FI correlated negatively with FmaxAvg.
Fmax values were higher in standard sculling in both subjects. We produced by a synchronized swimmer and a female swimmer in Our pilot study in which the force values, almost all the synchronized swimmers reached higher values of swimming.

phases, in opposition to the sculling technique that only have two phases of the front crawl underwater phases; (ii) higher front amplitudes of the front crawl underwater phases; (iii) stronger propulsion continuity, due to the existence of three underwater phases, in opposition to the sculling technique that only have two phases (Rackham, 1974) and (iii) the use of both upper and lower limbs during swimming.

Accordingly to the significant difference found between mean values, almost all the synchronized swimmers reached higher values of Fmax in standard sculling comparing to the contra-standard condition. A similar result was observed in our pilot study in which the force values produced by a synchronized swimmer and a female swimmer in standard and contra-standard sculling were compared (Diogo et al., in press). Fmax values were higher in standard sculling in both subjects. We hypothesized that this higher Fmax production in standard sculling may be due to a higher resemblance of the standard sculling with the swimming movements and to the possibility of being a more "natural" action from the anatomical point a view.

Earlier studies conducted in swimming showed that the relationship between the maximal, mean and minimum forces exerted during the tethered swimming test varies according to age, maturational state and competitive level (Sidney et al., 1996; Vorontsov et al., 1999; Morouço et al., 2008). Indeed, the difference in age and maturational state may contribute to explain the differences in force levels attained by our subjects. The correlation value obtained between age and the other variables showed a significant relationship with Fmax only in contra-standard sculling. Height can be another explanation for the above-referred results, as there is a direct relationship between this parameter and peak force (Risch and Castro, 2007). Eventually, longilineal individuals produce lower values of hydrodynamic resistance, reflecting higher peak forces values in tethered swimming (Toussaint and Beek, 1992), which is consistent with the significant relationship between body height and Fmax obtained in the present study. However, once in tethered swimming the displacement of the swimmer relatively to the water is null, this effect is more likely related to a scaling effect, being the functionality of muscles related to the square, or the cube of the linear dimensions (depending on considering the muscle cross sectional area or the muscular volume).

There may also be other factors that may influence the sculling force production, namely the hand configuration, regarding hydrodynamic characteristics, which can provide different production of lift force constraining the best performance (Ito, 2006). Additionally, the relative contribution of the hand to the propulsive force is dependent on the arm configuration (Lauder and Dabnichki, 2005). Unfortunately, we did not dispose of video images during the tethered swimming test, which would enable a detailed analysis of the sculling movement. However, we dispose of the arm span measurements. In fact, since it is commonly accepted that longer limbs will imply higher propulsion, it was not surprising to observe a high direct relationship between arm span and Fmax. Moreover, it is known that the differences in force level can also be explained by differences in technical level (Risch and Castro, 2007). However, this relationship can only be tested with the use of video images during the tethered swimming test, which will enable a detailed analysis of the sculling movement.

Morouço et al. (2008) mentioned that swimmers who reach high peaks of force are not able to maintain it for long periods of time. This statement is not supported by the present data, since an inverse relationship were observed between FI and FmaxAvg and Fmean (standard action), and with relative Fmax (contra-standard action). In contrast, FI presented significant negative correlation values with FminAvg in both sculling conditions, which means that fatigue is less visible in the swimmers who have higher average of minimum peak forces. This result appeals for a kinematic plus tethered force production combined analysis of the sculling movement, once swimmers with higher FminAvg seem to be more proficient.

CONCLUSION

The principal difference observed in force production between standard and contra-standard sculling was found for Fmax, with its absolute and relative values being higher for standard sculling. Mean force decreased during the 30 s effort in all participants and in both sculling conditions.

REFERENCES


Table 2. Individual and Mean ± SD values of absolute maximal (Fmax) and relative (relative Fmax) force, the time when the Fmax occurred (FmaxTime), mean force (Fmean), the average of maximal and minimum forces (FmaxAvg and FminAvg, respectively) and the fatigue index (FI) in contra-standard sculling (n=13).

<table>
<thead>
<tr>
<th>Swimmer</th>
<th>Fmax (N)</th>
<th>Relative Fmax (N/Kg)</th>
<th>FmaxTime (s)</th>
<th>Fmean (N)</th>
<th>FminAvg (N)</th>
<th>FmaxAvg (N)</th>
<th>FI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>32.2</td>
<td>0.63</td>
<td>2.3</td>
<td>15.5</td>
<td>8.3</td>
<td>24.4</td>
<td>66.2</td>
</tr>
<tr>
<td>#2</td>
<td>37.2</td>
<td>0.71</td>
<td>4.1</td>
<td>21.4</td>
<td>17.0</td>
<td>25.9</td>
<td>34.3</td>
</tr>
<tr>
<td>#3</td>
<td>30.4</td>
<td>0.53</td>
<td>4.8</td>
<td>15.5</td>
<td>11.3</td>
<td>19.5</td>
<td>41.9</td>
</tr>
<tr>
<td>#4</td>
<td>31.1</td>
<td>0.70</td>
<td>9.6</td>
<td>16.6</td>
<td>12.2</td>
<td>20.6</td>
<td>40.6</td>
</tr>
<tr>
<td>#5</td>
<td>32.9</td>
<td>0.73</td>
<td>4.9</td>
<td>13.5</td>
<td>11.5</td>
<td>18.5</td>
<td>37.7</td>
</tr>
<tr>
<td>#6</td>
<td>35.4</td>
<td>0.80</td>
<td>3.4</td>
<td>16.2</td>
<td>13.9</td>
<td>20.0</td>
<td>30.4</td>
</tr>
<tr>
<td>#7</td>
<td>41.9</td>
<td>0.67</td>
<td>3.1</td>
<td>15.8</td>
<td>11.9</td>
<td>20.8</td>
<td>42.8</td>
</tr>
<tr>
<td>#8</td>
<td>24.0</td>
<td>0.72</td>
<td>2.9</td>
<td>12.5</td>
<td>10.5</td>
<td>14.7</td>
<td>29.0</td>
</tr>
<tr>
<td>#9</td>
<td>30.0</td>
<td>0.67</td>
<td>6.9</td>
<td>16.3</td>
<td>14.7</td>
<td>19.3</td>
<td>23.7</td>
</tr>
<tr>
<td>#10</td>
<td>34.0</td>
<td>0.64</td>
<td>6.2</td>
<td>18.9</td>
<td>13.7</td>
<td>25.4</td>
<td>47.2</td>
</tr>
<tr>
<td>#11</td>
<td>41.6</td>
<td>0.69</td>
<td>2.5</td>
<td>24.3</td>
<td>18.6</td>
<td>32.7</td>
<td>43.2</td>
</tr>
<tr>
<td>#12</td>
<td>35.8</td>
<td>0.66</td>
<td>8.1</td>
<td>19.1</td>
<td>16.8</td>
<td>23.8</td>
<td>29.2</td>
</tr>
<tr>
<td>#13</td>
<td>40.8</td>
<td>0.82</td>
<td>3.9</td>
<td>23.4</td>
<td>19.6</td>
<td>26.5</td>
<td>26.2</td>
</tr>
</tbody>
</table>

X ± SD 34.6±5.4 0.69±0.07 4.8±2.3 17.6±3.6 13.8±3.4 22.5±4.6 37.9±11.3

*Different (p<0.05) from respective value of standard sculling (Table 2).

Figure 1. Example of an individual F(t) curve (unfiltered data) in standard sculling. The cut point of the two first s of force values, correspondent to the first pull, is marked.


**Pulling Force Characteristics of 10 s Maximal Tethered Eggbeater Kick in Elite Water Polo Players: A Pilot Study**

Dopsaj, M.

University of Belgrade, Faculty of Sport and Physical Education, Serbia

This paper aimed to define the basic kinetic and mechanical characteristics of 10 s maximal tethered eggbeater kicks in elite water polo players in the chest-forward position with hands above the water. The study involved 14 male elite water polo players. The following measurements of the kinetic characteristics of pulling force were taken: the duration of a single leg eggbeater kick, the maximal (peak) force values, the average force values, the impulse of force, the single leg eggbeater kick rate of force development and the single leg eggbeater kick frequency. Reliability analysis showed high statistical significance of the measurement results of the test at ICC=0.9681. Besides, the pulling force realized at FmaxEBK and FavgEBK was determined to have changed significantly at the time interval of 10s. The resulting models could help towards the development of the water polo training technology, as well as the establishment of a new method to test the specific leg fitness in elite senior water polo players.

**Key words:** eggbeater kick, tethered pulling force, water polo

**INTRODUCTION**

Water polo players realize all of their technical and tactical (TE-TA) tasks from two basic positions in the water: the horizontal and the vertical position (Dopsaj & Thanopoulos, 2006). Although the general physiological load indicators categorize water polo as a sport that requires a high level of aerobic endurance, a great number of TE-TA activities are realized through the maximal interval intensity in shorter intervals in which the energy is dominantly supplied by an anaerobic-alactic system – the ATP/CP system (Smith, 1998).

Calculations, based on time and motion analysis, have indicated that field players spend only 45% to 55% of game time in the horizontal body position. The remainder of the time is spent performing activities in predominantly vertical body positions, with or without contact with the opponent, and with a moderate to high intensity, as indicated by heart rate recordings in some studies (Platanou, 2009).

In water polo, duel play is the players’ basic position in both the offense and the defense. The position essentially enables players to block the opponent by holding their arms so as to perform the TE-TA elements, using the eggbeater kick technique simultaneously (Sanders, 1999; Dopsaj & Thanopoulos, 2006). Essentially, the eggbeater kick is also used to raise the upper body for the purpose of receiving a pass, passing, shooting for goal, or blocking the opponent’s shooting, passing or receiving actions. The eggbeater kick is a cyclic action of the lower limbs with the actions of the right and left sides being similar but opposite in phase, meant to sustain the body in the elevated position or to push the opponent’s body strongly (Sanders, 1999).

Previous studies have established that most water polo realizations from the vertical position, with or without contact with the opponent, are done at the maximal and/or submaximal effort intensity in the anaerobic lactate energy system (Smith, 1998; Platanou, 2004; Takagi et al., 2005; Platanou, 2009), which points towards the conclusion that the specific training of the lower extremities indirectly affects game effectiveness. However, so far no research has published studies of the pulling force characteristics realized in water and by eggbeater kick techniques within the effort system which is dominant in competitions.

This paper aimed to define the basic kinetic and mechanical characteristics of 10 s maximal tethered eggbeater kicks in elite water polo players in order to define a descriptive model of the characteristics measured in the population of highly trained water polo players.
METHODS
The study involved 14 male top senior national level water polo players (Age=21.5±5.1 yrs; Height=187.2±6.1 cm; Mass=84.5±11.9 kg; training experience=11.7±3.6 yrs). The tests were conducted in the middle of the national premier league preparation period for the 2006/07 competition season. Egg beater kick pulling force was tested by the method of tethered swimming (Sidney et al., 1996; Dopsaj et al., 2003). Before the test the players warmed up swimming independently up to 400m, and did 10 min of specific water polo warm-up in the vertical position with the emphasis on eggbeater kick exercises. After a 10 min rest the testing procedure started. On his turn, each player put on a belted harness adjusting it to his body size. Then he hooked a 1cm-thick PVC rope to the belt at back hip region. The other end of the 5m rope was attached to a water-resistant high-resolution (100 kHz) tensiometric dynamometer placed on a metal support fixed on the side of the pool (Dopsaj et al., 2003). The dynamometer was connected to a PC. After they entered the pool, the players did a 15s pre-test trial of eggbeater kick tethered swim at self chosen intensity in order to get familiar with the equipment and the testing procedure. After the 1 min rest, testing procedure started, where the players had to realize the one test trial of maximal pull force of 10 seconds using eggbeaters kicks only while in the chest-forward position, with hands above the water wrist-high, in semi-flexed position and in front of the shoulders, i.e. the chest. The following measurements of the kinetic characteristics of pulling force at a single leg eggbeater kick were taken: the duration (TimeEBK), expressed in ms; the realized maximal (peak) force value (F_{maxEBK}), expressed in N; the average realized force value (F_{avgEBK}), expressed in N; the impulse of force (ImpF_{EBK}), expressed in N·s; the explosive rate of force production (RFDEBK), expressed in N·s^{-1}; and the frequency (Hz_{EBK}), expressed in the numbers of single leg kicks per minute (Slk·min^{-1}). All data were treated in absolute and relative values with the descriptive statistical method. Linear regression analysis was used to define a model of variable change during the testing time. Since the testing method had not been previously used for eggbeater kick techniques, the reliability was determined by applying reliability analysis with Split-half model criteria.

RESULTS
All descriptive data are shown in Table 1 (Mean, Standard Deviation and Coefficient of Variation). The reliability analysis showed that the resulting measurements of pulling force parameters of 10s maximal tethered egg beater kick were highly statistically significant at 96.81% (Spearman-Brown rt coefficient – 0.9681), with Interclass Correlation Coefficient at single measurements IC= 0.994, F=157.63, p=0.000, and at average measurements IC= 0.994, F=157.63, p=0.000.

Table 2 gives the results of the defined regression models showing the dependence in the change of tethered pulling force characteristics in 10s (where: y values are variable units; x values are observed time intervals in ms). Statistical significance was determined in only two variables, F_{maxEBK} and F_{avgEBK} at the level of F=26.21, p=0.000 and F=43.95, p=0.000, respectively.

Figure 1 gives the F-t curve tethered eggbeater pulling force of two players playing in different positions (central defender and peripheral player), while Figure 2 is a graphic representation of the observed tethered force pulling characteristics with the regression lines showing the trend of change.

DISCUSSION
In comparison with the absolute values, the variation coefficient showed high homogeneity in all tested variables, with the value of all variables below 30 % (from 11% with Time_{EBK} to 29% with RFDEBK). The rela-

Table 1. The descriptive statistics of 10 s maximum chest-forward tethered single leg eggbeater kick

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time_{EBK} (ms)</td>
<td>497.78</td>
<td>190.52</td>
<td>12.37</td>
</tr>
<tr>
<td>F_{maxEBK} (N)</td>
<td>205.92</td>
<td>0.880</td>
<td>11.44</td>
</tr>
<tr>
<td>F_{avgEBK} (N)</td>
<td>159.20</td>
<td>0.214</td>
<td>12.04</td>
</tr>
<tr>
<td>F_{impEBK} (N·s)</td>
<td>75.71</td>
<td>1.610</td>
<td>19.64</td>
</tr>
<tr>
<td>F_{imprelEBK} (N·s·kg^{-1})</td>
<td>0.28</td>
<td>0.006</td>
<td>23.26</td>
</tr>
<tr>
<td>F_{avgrelEBK} (N·s·kg^{-1})</td>
<td>0.16</td>
<td>0.004</td>
<td>11.44</td>
</tr>
</tbody>
</table>

Figure 1. Tethered eggbeater 10 s maximal pulling force in the chest-forward position in the two players (central guard – red line; peripheral – black line).

Figure 2. Linear regression trend line models of tethered eggbeater 10 s maximal pulling force characteristics in the chest-forward position in the peripheral player.

Table 2. The linear regression model equation of 10 s maximum chest-forward tethered leg eggbeater kick for all observed pulling force variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model</th>
<th>Adj. R²</th>
<th>F and p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time_{EBK} (ms)</td>
<td>y = -0.0035x + 467.8753</td>
<td>R² = 0.086</td>
<td>F=0.793, p=0.382</td>
</tr>
<tr>
<td>F_{maxEBK} (N)</td>
<td>y = -0.0003x + 205.9223</td>
<td>R² = 0.512</td>
<td>F=26.21, p=0.000</td>
</tr>
<tr>
<td>F_{avgEBK} (N·s)</td>
<td>y = -0.0010x + 159.2081</td>
<td>R² = 0.641</td>
<td>F=43.95, p=0.000</td>
</tr>
<tr>
<td>RFD_{EBK} (N·s^{-1})</td>
<td>y = -0.0037x + 0.757146</td>
<td>R² = 0.086</td>
<td>F=2.71, p=0.113</td>
</tr>
<tr>
<td>F_{impEBK} (N·s)</td>
<td>y = -0.0037x + 0.1592081</td>
<td>R² = 0.641</td>
<td>F=43.95, p=0.000</td>
</tr>
<tr>
<td>F_{imprelEBK} (N·s·kg^{-1})</td>
<td>y = -0.0035x + 328.7769</td>
<td>R² = 0.018</td>
<td>F=0.573, p=0.457</td>
</tr>
<tr>
<td>Hz_{EBK} (Slk·min^{-1})</td>
<td>y = -0.0006x + 140.1895</td>
<td>R² = 0.006</td>
<td>F=0.071, p=0.793</td>
</tr>
</tbody>
</table>
The main force that keeps the water polo players suspended in the water while performing other skills is hydrodynamic lift force, which is caused by the flow of water over the foot and leg of the athlete. With respect to the obtained descriptive indicators, it can be maintained that the interval at 95% likelihood in assessing the training level of the anaerobic capacity caused by the flow of water over the foot and leg of the athlete. With respect to the basic kinetic indicator, i.e., the duration of a single eggbeater kick, it was established that it ranged from 441 to 555 ms; FmaxEBK = 155 – 227 N; FavgEBK = 119 – 162 N; ImpFEBK = 59 – 87 N s; RFDrelEBK = 238 – 436 N s^{-1}; HZEBK = 107 – 137 Slk min^{-1} for absolute values of the single leg eggbeater kick. At the reliability rate of 95%, the descriptive variable results yielded the following relative values: FrelEBK = 1.76–2.83 N kg^{-1}; FavgrelEBK = 1.36–2.02 N kg^{-1}; ImprelEBK = 0.67–1.09 N s kg^{-1}; RFDrelEBK = 2.49–5.72 N s^{-1} kg^{-1} for relative values of the single leg eggbeater kick.

With respect to the basic kinetic indicator, i.e., the duration of a single eggbeater kick, it was established that it ranged from 441 to 555 ms at the likelihood level of 95% (average TimeEBK value ± SD value). As compared to the results published by Marion & Taylor (2008), the time for one complete eggbeater kick cycle was between 0.5 sec and 0.65 sec. However, here the authors studied the eggbeater kick technique with the athletes in vertical position, while in the present study the water polo players realized the maximal pull force within 10 s in the semi-vertical chest-forward position. It is possible that the ensuing difference in the duration of a single leg cycle was due to the different measurement methods as well as to the nature of the task and the intensity of legwork under load.

A study of the vertical force exerted during the eggbeater kick in water polo concluded that the vertical force of the kick ranged from 60 to 112 N (Yanagi, Amano et al. 1995, as cited in Marion & Taylor, 2008). According to Marion & Taylor (2008) for an athlete with a weight of 600 N, the eggbeater contributes in 10–20% of the upward mass. The current study established that senior top water polo players’ averages of maximal single leg eggbeater kick pull force (peak force) can be achieved with maximal effort in 10 s at the average level of 190±36 N, i.e. ranging between 155 and 227 N with 95% reliability. Moreover, the rate of force development of the eggbeater kick was shown to be at the level ranging between 238 – 436 N s^{-1} with 95% likelihood level. In our results, the average BM was 84.5 kg and the pulling force realized by the given method was at the level of 23.40±5.44 % of the subjects’ BMI, i.e. within the reliability range of 18.0 to 28.8%. Presumably, all the measured kinetic characteristics of legwork in the given water polo technique are due to the years of the players’ adaptation to the exertions of training and competition so that the experimental results can represent an actual model of the players’ abilities to cope with the task given in the test. New water polo rules introduced in 2006 resulted in more intensive competitor efforts, especially for technical and tactical elements where legwork is the dominant movement (eggbeater, jumps, shots, duel play and defender actions) for which players must be prepared through an adequate system of training (Platanou, 2009). Such data indicate that more intensified training and the introduction of specific changes in the training work are necessary to achieve best results in water polo, especially in vertical and semi-vertical water polo positions. Besides, the approach given here highlights the demand for defining specific methods to test the abilities of water polo players.

CONCLUSION

The results indicated the descriptive values of the kinetic characteristics of the 10s maximal tethered eggbeater kick in elite water polo players with regard to the absolute and relative values. The reliability analysis showed that the reliability of measuring the pulling force characteristics of 10s maximal tethered egg beater kick was highly statistically significant at 96.81%, with ICC at single measures = 0.918, and at ICC average measures = 0.994. It was also established that only two variables of the measured value showed statistically significant change in the time interval of 10s, namely FmaxEBK and FavgEBK. In our results, the average tethered pull force peaked at 23.40±5.44 % of the subjects’ body mass.

Moreover, the resulting data could also help towards the development of water polo training technology, and the establishment of a new method to test the specific leg fitness in elite senior water polo players.

REFERENCES


Marion, A., & Taylor, C. (2008). The technique of the eggbeater kick. (39.21 %). The descriptive and variation indicators can be used as scientifically valid for further comparative analysis.
Motor Coordination During the Underwater Undulatory Swimming Phase of the Start for High Level Swimmers

Elipot, M. 1,2, Houel, N. 2, Hellard, P. 2, Dietrich, G. 1

1Université Paris Descartes, Paris, France
2Fédération française de natation, Paris, France

The aim of the present study was to identify the main motor coordination involved during the underwater undulatory swimming phase of the start. Twelve French high-level swimmers took part in this study. Swimmers were filmed during the entire underwater phase of the start (i.e. fifteen meters from the start platform). Specific anatomical landmarks were identified on the body of the swimmers and 2D space coordinates of these landmarks were calculated. Cross correlation functions were used to investigate the motor coordination between the actions of the hip, the knee and the ankle. Results show that high-level swimmers regulate the leg amplitude thanks to a strong synergy between the hip and the ankle and an independent action of the knee.

Key words: Motor control, start, underwater undulatory swimming

INTRODUCTION

High-level athletes are characterised by superior tactical, physical and technical levels. Improving one of these factors will lead to a performance improvement. As in many other sports, swimming performance is strongly linked to the technical level of the swimmers. Swimming performance optimisation requires an accurate analysis of the swimmers’ movement. Biomechanics and motor control sciences give useful tools to realise such analysis. Motor control theories, and more especially the joint synergies theories, will indeed help to understand how high level swimmers are able to produce specific, appropriate and efficient motor pattern.

Many previous researches have already shown that start performance is determinant to achieve a good race performance. Depending on the studies, start performance is defined as the time to complete the 10 or 15 first meters from the start wall (Alves, 1993; Arellano et al., 1996; Mason and Cossor, 2000). The start consists of 3 phases: the impulsion phase, the aerial phase and the underwater phase (Maglischo, 2003). This underwater phase of the start could be divided in 2 phases, i.e. the glide phase and the underwater undulatory swimming phase (Maglischo, 2003).

During the glide, swimmers aim to keep the supra-maximal velocity created during the impulsion and aerial phases as high as possible and as long as possible. A previous study has already shown that during the glide phase high level swimmers presented a strong joint synergy between the shoulders, the hip and the knee (Elipot et al, 2009). It seems that with this synergic action of those three joints high level swimmers are able to hold a streamlined position during the whole glide phase. Hydrodynamic resistance are decreased and supra-maximal velocity is kept longer. During the underwater undulatory swimming, the swimmers’ aim is to produce velocities with leg action. Swimmers have then to find the optimal compromise between the amplitude and the frequency of the leg undulatory movements (Arellano, 2008). Swimmers have to find the optimal compromise between propulsion force creation and hydrodynamic resistance decrease. Identifying the motor coordination during this underwater undulatory swimming phase of the start is a major step to understand and optimise this phase.

The aim of this study was to determine the motor coordination that high-level swimmers are able to produce during the underwater undulatory swimming phase of the start.

METHODS

Subjects and instructions:

Twelve male swimmers participated in this study. All were informed of the aim of the study and signed a consent form. All participants were high-level swimmers and were members of the French National Swimming Team. Swimmers’ characteristics are summarized in Table 1.

The best start was analysed (i.e. the best time to complete 15 meters from the start wall). All swimmers were regularly trained to perform this kind of start and use it during competition.

Experimental set up and data analysis:

Swimmers were filmed by 4 mini-DV camcorders (576x720 pixels) during the whole underwater phase of the start (i.e. fifteen meters from the start platform) (Fig. 1). The camcorder 1, 2 and 3 were placed the swimming pool portholes and the camcorder 4 was placed in the water in a waterproof housing. The camcorders position has been chosen so as to minimise reconstruction error due to optical distortions (Snell law). All camcorders were synchronised using a light signal and sampling frequency was 25Hz. Images were deinterlaced and odd and even fields were both used.

Nine anatomical landmarks were identified on swimmer’s body: the toe, the lateral malleolus, the knee, the iliac spine, the acromion, a finger hip, the wrist, the elbow and the centre of the head. To minimise the error during the digitising process, only the right side of the swimmers has been identified. Both sides were supposed to be symmetric. Using a modified DLT 2D technique (inspired from Drenk et al., 1999) and the Dempster anthropometric data (Dempster, 1959), joints’ positions and swimmers’ centre of mass position have been calculated. Reconstruction error was calculated as indicated by Kwon and Casebolt (2006). Mean reconstruction error was 6.2 mm and maximal reconstruction error was 12.2 mm. Data were filtered using a Butterworth II filter (Winter, 1990). Cut-off frequencies were included between 5 Hz and 7 Hz.

Table 1. Swimmers’ general characteristics (n = 12).

<table>
<thead>
<tr>
<th>Swimmers’ characteristics</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
<th>Best performance (freestyle) 50-m (s)</th>
<th>50-m (%i)</th>
<th>100-m (s)</th>
<th>100-m (%i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.83</td>
<td>76.1</td>
<td>24.39</td>
<td>116.47</td>
<td>52.26</td>
<td>111.4</td>
</tr>
<tr>
<td>SD</td>
<td>4.89</td>
<td>5.18</td>
<td>1.26</td>
<td>6.02</td>
<td>1.68</td>
<td>3.57</td>
</tr>
</tbody>
</table>

Swimmers were asked to perform 3 grab starts as fast as possible. Only the best start was analysed (i.e. the best time to complete 15 meters from the start wall). All swimmers were regularly trained to perform this kind of start and use it during competition.

To avoid between-subjects variations due to the slope of the trajectory to reach the water surface, data were expressed in a (O’, n, t, b) local reference frame attached to the swimmers’ centre of mass and with n collinear to the velocity vector and t perpendicular to n (Fresney frame of reference). During the whole underwater phase, the velocity of the centre of mass, the joint positions, velocities and angles for the hip, the knee and the ankle, the angles between the x-axis and the limbs (angle of attack) were calculated. Only the joints longitudinal and vertical positions were expressed in the original global frame (O, x, y, z).

Motor coordination was investigated by computing the cross cor-
relation functions between all the calculated kinematics variables. These
kinematic data were represented in form of time-dependent signals. Re-
results were obtained using Matlab software (The Matworks Inc., USA).
Level of confidence was set at 95% (p<0.05).

RESULTS
Cross-correlation functions result did not show any significant correla-
tion between the swimmers centre of mass velocity and other kinematics
variables (i.e. joint angles or joint vertical accelerations). Significant
cross-correlation are summarised in Table 2. Cross correlation values
and lag value are mean values. Three examples of cross correlation func-
tions are also given in Figure 2.

Table 2. Significant cross correlation functions (p<0.05).

<table>
<thead>
<tr>
<th>First kinematic signal</th>
<th>Second kinematic signal</th>
<th>Cross correlation value (r)</th>
<th>Lag (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip angle</td>
<td>Ankle angle</td>
<td>0.75</td>
<td>-19</td>
</tr>
<tr>
<td>Hip angle</td>
<td>Trunk angle</td>
<td>-0.77</td>
<td>18</td>
</tr>
<tr>
<td>Hip angle</td>
<td>Thigh angle of attack</td>
<td>-0.72</td>
<td>3.2</td>
</tr>
<tr>
<td>Knee angle</td>
<td>Thigh angle of attack</td>
<td>-0.74</td>
<td>32</td>
</tr>
<tr>
<td>Knee depth</td>
<td>Thigh angle of attack</td>
<td>-0.74</td>
<td>7.5</td>
</tr>
<tr>
<td>Knee depth</td>
<td>Hip angle</td>
<td>0.73</td>
<td>50</td>
</tr>
<tr>
<td>Knee depth</td>
<td>Knee angle</td>
<td>0.81</td>
<td>6</td>
</tr>
<tr>
<td>Hip angle</td>
<td>Leg angle of attack</td>
<td>0.69</td>
<td>33</td>
</tr>
<tr>
<td>Knee angle</td>
<td>Leg angle of attack</td>
<td>-0.85</td>
<td>16</td>
</tr>
<tr>
<td>Angle depth</td>
<td>Hip angle</td>
<td>0.82</td>
<td>-21</td>
</tr>
<tr>
<td>Ankle depth</td>
<td>Knee angle</td>
<td>0.82</td>
<td>-22</td>
</tr>
<tr>
<td>Toes depth</td>
<td>Hip angle</td>
<td>-0.64</td>
<td>8</td>
</tr>
<tr>
<td>Toes depth</td>
<td>Knee angle</td>
<td>0.75</td>
<td>74</td>
</tr>
<tr>
<td>Toes depth</td>
<td>Ankle angle</td>
<td>-0.76</td>
<td>16</td>
</tr>
</tbody>
</table>

Figure 2. Examples of cross correlation functions

DISCUSSION
To achieve the best performance during the underwater undulatory
swimming phase the start, swimmers have both to produce the high-
est propulsive forces, and decrease the hydrodynamic resistances. The
leg amplitude control is one of the most important factors involved in
this problem. By increasing the leg amplitude, swimmers create a big-
ger wake of counter-rotation vortices and maximise the leg propulsion.
Nevertheless, when leg amplitude increase, the swimmer’s form drag
will also increase. Leg amplitude is caused by the actions of the hip, the
knee and the ankle. A previous study showed that national level swim-
ners score lower maximal knee angles than regional level swimmers
(Arellano et al., 2003). Nevertheless, our study did not succeed to show
significant cross-correlations between any kinematic variables and the
swimmer’ centre of mass velocity (even for the knee angle). Two main
reasons could explain these results: 1- The velocities observed during the
underwater undulatory phase are not only due to the leg action but also
result of the velocities created during the impulsion and aerial phases.
2- The velocities created could not be simply explained by one factor.
Velocity production during the undulatory is a complex phenomenon
involving a coupled action of many joints. Moreover, the cross-correla-
tion functions are not designed to measure these kinds of interactions.

Studying fin swimming technique using artificial neural networks,
Rejman et al. (2005) have shown that swimmers centre of mass velocity
is determined by the angle of attack accelerations of the fin, the angle
of attack of the fin and the knee angular velocity (flexion and exten-
sion). The artificial neural network could be an interesting technique to
multiple time-dependant factors correlations. Nevertheless, the results
obtained for the single fin swimming cannot be applied to the underwa-
ter undulatory swimming phase after a start. Single fin swimming and
underwater undulatory swimming are two different motor tasks with
their own specific motor coordination.

The present study results show that high-level swimmers have a spe-
cific motor coordination leading to low joint angles. High-level swim-
ners present a strong joint synergy between hip and ankle action. Knee
action is also important but seems to have an independent effect on leg
amplitude. Indeed, when the hip-ankle action increases, the toes and the
ankle go down and the trunk and leg attack angles increase and, form
drag increases. Nevertheless, in parallel, knee action leads to an increase
angle of attack of the thigh, which causes a decrease of the hip-ankle
action.

A synergic action of the hip, the knee and the ankle would have
lead a much bigger leg amplitude and then to a much bigger form drag
increase. High-level swimmers seem actually to adopt a regulation loop
in which the hip-ankle action and the knee action are independent and
which control the leg amplitude.

CONCLUSION
The present study shows that, during the underwater undulatory swim-
mimg, high level swimmers are able to adopt a specific motor coordina-
tion. Indeed, high level undulatory movements are characterized by a
strong synergy between hip and ankle action.

REFERENCES
Congress of International Society of Biomechanics (pp. 88-89). Paris, In-
ternational Society of Biomechanics.
arial analysis of the starting technique in freestyle swimming. In: J.
Abrantes (Ed.), Proceedings of the XIVth International Symposium on
Biomechanics in Sports (pp. 289-292). Lisboa, Universidade Tecnica
de Lisboa.
Arellano, R., Pardillo, S. & Gavilan, A. (2003). Usefulness of the Strou-
hal Number in Evaluating Human Underwater Undulatory Swim-
mimg. In J. C. Chatard (Ed.), Biomechanics and Medicine in Swimming
IX (pp. 33-38). Saint-Etienne: Université de Saint-Etienne.
Sidney, E. Postevin, & P. Pelayo (Eds.), Proceedings of the XIVth Journees
Spécialisées de Natation (pp. 21-35). Lille: Université de Lille.
Dempster, W. T., Gabel, W. C. & Pets, W. J. L. (1959). The anthropom-
etry manual work space for the seated subject. American Journal of
Physiology and Anthropometry, 17, 289-317.
technique for analysis of swimming in a flume. In R.H. Sanders, &
B.J. Gibson (Eds.), Proceedings of the XVII International Symposium on
(2009). Analysis of swimmers’ velocity during the underwater gliding
motion following a grab start. Journal of biomechanics, 42, 1367-1370.
ACKNOWLEDGEMENTS
The authors wish to thank the "Ministère de la Jeunesse, des Sports et de la Vie Associative" and the "Fédération Française de Natation" for financing this study. The authors also wish to thank Frédéric Frontier, Frédéric Clerc, Isabelle Amaudry and Yves Thomasin for their contributions.

Relationship between Arm Coordination and Energy Cost in Front Crawl Swimming


1University of Porto, Faculty of Sport, Gif2d, Portugal
2Finnish Society of Sport Sciences, Finland
3University of Rouen, Faculty of Sport Sciences, France

The aim of the study was to assess the relationship between the Index of Coordination (IdC) and the Energy Cost of exercise (C) in front crawl swimming. Seven high level swimmers performed a paced intermittent incremental protocol of 7 × 200 m (0.05 m·s⁻¹ increments, 30 s intervals), until maximal oxygen consumption intensities. IdC was assessed as the time gap between the propulsion of the two arms. Oxygen consumption was measured through direct breath×breath oximetry and lactate analyses were conducted at rest, in the intervals and at the end of exercise. Along the protocol, concomitant with the velocity raise, both C and IdC increased (r=0.98 and r=0.99, p<0.01, respectively). A very high relationship was also observed between IdC and C (r=0.99, p<0.01). However, when removing the effect of velocity, the relationship between IdC and C was not significant.

Key words: elite swimmers, energy cost, index of coordination

INTRODUCTION
Performance in swimming is measured by the time that the swimmer needs to cover a specific distance. The capacity to reach and maintain a given velocity is highly dependent on biomechanical and physiological parameters. Among the biomechanical factors, the influence of the stroking parameters (stroke rate and stroke length) on swimming performance is well reported in the literature (Keskinen and Komi, 1993; Wakayoshi et al, 1995). Furthermore, it was shown that the temporal organization of the stroke is also important to characterise highly skilled performance swimmers (Chatard et al., 1990). More recently, attention has been given to these modifications on temporal organisation of arm stroke phases and arm coordination, assessed by the Index of Coordination (IdC), initially proposed by Chollet et al. (2000). The IdC in front crawl is based on the lag time between the propulsive phases of each arm, which quantifies three possible coordination modes (Chollet et al., 2000): opposition (continuity between two arm propulsions, IdC = 0%), catch-up (a time gap between the two arm propulsions, IdC < 0%) and superposition (an overlap of the two arm propulsions, IdC > 0%). According to Seifert et al. (2007), the arm coordination in swimming is influenced by some constraints: environmental constraints (e.g. active drag and velocity), task constraints (pace imposed, goal, instructions or rule of the task) and organism constraints (the swimmer speciality, anthropometric characteristics and gender). In addition to these constraints, it is also hypothesized that physiological parameters could influence the arm coordination in front crawl, being IdC sensitive to metabolic fatigue (Alberty et al., 2005). Thus, an increase in the IdC values seems not to be exclusively linked to an increase in velocity or to the above-referred factors. In fact, it is admissible that other parameters could explain the raise of the IdC values concomitant with the increase of swimming intensity (such as some physiological parameters). The idea that, physiological parameters could influence coordinative and biomechanical parameters (and vice-versa), has already been suggested, i.e. swimming economy is highly correlated with biomechanical parameters (Chatard et al., 1990; Vilas-Boas, 1996). More recently, it was also reported that the stroke mechanics are highly correlated with the energy cost of exercise (C) (Barbosa et al, 2008), a parameter generally used to quantify swimming economy.

The assessment of the C in swimming is well reported in the literature since the 1970s, and is considered as the total energy expenditure required...
for displacing the body over a given unit of distance (Zamparo et al., 2005). Furthermore, it is accepted as an important bioenergetical determinant of swimming performance (Wakayoshi et al., 1995; Kjendal et al., 2004; Fernandes et al., 2006). However, the body of scientific literature needs approaches on the relationships between the IdC and the C in trying to understand how these two variables may be connected. The present study aimed at assessing relationships between the IdC and the C in front crawl, especially at intensities ranging between ~70% and 100% of the maximal oxygen consumption (\(\dot{V}O_{2\text{max}}\)). We hypothesised that if velocity is controlled, IdC and C are inversely related.

**METHODS**

Seven high-level swimmers (17.0 ± 1.8 years; 168.0 ± 8.8 cm; 58.4 ± 8.2 kg) participant in national swimming championships were tested. Mean (± SD) main physiological characteristics were: 18.0 (6.9) % of fat mass, 54.9 (10.1) ml·kg·min⁻¹ of \(\dot{V}O_{2\text{max}}\) and 7.5 (2.4) of blood lactate concentrations ([La⁻]) at intensities corresponding to \(\dot{V}O_{2\text{max}}\). In an indoor 25 m swimming pool, the participants performed an intermittent incremental protocol, with increments of 0.05 m·s⁻¹ each 200 m stage (and 30 s intervals), until exhaustion (Fernandes et al., 2003). Initial velocity was established according to the individual level of fitness and was set at the swimmer's individual performance on the 400 m freestyle minus seven increments of velocity. Swimming velocity was controlled using a visual pacer (TAR 1.1, GBK-electronics, Aveiro, Portugal) with successive flashing lights, 2.5 m apart, on the bottom of the pool.

\(\dot{V}O_{2}\), was measured through direct breath-by-breath oximetry (K4 b², Cosmed, Rome, Italy) connected to the swimmer by a respiratory snorkel and valve system (Keskinen et al., 2003). Capillary blood samples (25 µl) for [La⁻] analysis were collected from the earlobe at rest, in the 30 s rest interval, at the end of exercise and during the recovery period (YSI1500L-Sport auto-analyser, Yellow Springs Incorporated, Ohio, USA). The C was calculated by dividing total energy expenditure (\(\dot{E}\)) by velocity (v) and converted to SI units, were 1 ml\(O_2\) is equivalent to 20.1 J (Zamparo et al., 2005; Fernandes et al., 2006):

\[
C = \frac{\dot{E}}{v} \quad (1)
\]

The \(\dot{E}\) corrected for body mass was calculated using the \(\dot{V}O_{2\text{net}}\) (difference between the value measured in the end of the stage and the rest value), and the blood lactate net (difference between the value measured in two consecutive stages) transformed into \(\dot{V}O_{2\text{equiv}}\) equivalents using a 2.7ml\(O_2\), kg⁻¹·min⁻¹ proportionality constant and by Equation (2) (cf. Fernandes et al., 2006)

\[
\dot{E} = \dot{V}O_{2\text{net}} + [La^{-}] \text{net} \quad (2)
\]

Two video cameras (JVC GR-SX1 SVHS and JVC GR-SXM 25 SVHS) were fixed on the lateral wall of the pool at a 10 m distance perpendicular to the swimmers’ plane of movement. The cameras were connected to a double entry and edited on a mixing table (Panasonic Digital Mixer WJ-AVE55 VHS), providing a dual-media image (Panasonic AG 7355), below and above the water surface (Vilas-Boas et al., 2006), at a frequency of 50 Hz (1:250/s shutter speed).

For each step of the incremental protocol, two arm strokes were analysed in every 50 m of the 200 m. Arm stroking coordination was obtained through IdC (Chollet et al., 2000), being each arm stroke broken down into four phases: (i) entry and catch (corresponding to the time between the entry of the hand into the water and the beginning of its backward movement); (ii) pull (corresponding to the time between the beginning of the hand’s backward movement and its arrival in a vertical plane to the shoulder); (iii) push (corresponding to the time from the position of the hand below the shoulder to its release from the water) and (iv) recovery (corresponding to the point of water release to water re-entry of the arm, i.e., the above water phase). The duration of each phase was measured for each arm-stroke cycle with a precision of 0.02 s. The duration of the propulsive phases was the addition of the pull and the push phases, and the duration of the non-propulsive phases was obtained by the sum of

- the catch and the recovery phases (the duration of a complete arm–stroke was the sum of the propulsive and non-propulsive phases). The IdC was calculated as the time gap between the propulsion of the two arms as a percentage of the duration of the complete arm stroke cycle. Higher negative percentage values expressed an evident discontinuity in the inter-arm propulsion, tending to IdC=0% as the time gap was diminishing.

Mean ± SD computations for descriptive analysis were obtained in each stage for all variables (all data were checked for distribution normality with the Shapiro-Wilk test). Pearson correlation coefficient and partial correlation were applied. Level of significance was established at 5%.

**RESULTS**

The mean ± SD values of velocity, % \(\dot{V}O_{2\text{max}}\), C, and IdC, obtained in each step during the intermittent incremental test, are presented in Table 1. An increase of swimming intensity implies an increase of both C and IdC (Table 1).

<table>
<thead>
<tr>
<th>Step</th>
<th>Velocity (m·s⁻¹)</th>
<th>% (\dot{V}O_{2\text{max}})</th>
<th>C (J·kg⁻¹·m⁻³)</th>
<th>IdC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.15 ± 0.1</td>
<td>72.1 ± 8.7</td>
<td>9.4 ± 2.5</td>
<td>-12.5 ± 2.5</td>
</tr>
<tr>
<td>2</td>
<td>1.20 ± 0.1</td>
<td>76.5 ± 9.1</td>
<td>10.3 ± 2.8</td>
<td>-12.1 ± 2.7</td>
</tr>
<tr>
<td>3</td>
<td>1.25 ± 0.1</td>
<td>77.8 ± 5.3</td>
<td>10.1 ± 3.0</td>
<td>-11.8 ± 2.6</td>
</tr>
<tr>
<td>4</td>
<td>1.30 ± 0.1</td>
<td>85.5 ± 3.3</td>
<td>11.5 ± 3.2</td>
<td>-10.9 ± 2.6</td>
</tr>
<tr>
<td>5</td>
<td>1.35 ± 0.1</td>
<td>90.9 ± 3.2</td>
<td>12.7 ± 2.8</td>
<td>-9.7 ± 2.7</td>
</tr>
<tr>
<td>6</td>
<td>1.40 ± 0.1</td>
<td>97.3 ± 3.2</td>
<td>13.7 ± 2.4</td>
<td>-8.2 ± 2.7</td>
</tr>
<tr>
<td>7</td>
<td>1.45 ± 0.1</td>
<td>100.0 ± 0.0</td>
<td>14.0 ± 4.2</td>
<td>-6.8 ± 2.5</td>
</tr>
</tbody>
</table>

The relationships between velocity and C, and velocity and IdC are shown in Fig. 1 (left panel), being possible to observe a high correlation value between these variables (r=0.98 and r=0.99, respectively, both for p<0.01). A strong relationship exists also between IdC and C (r=0.99, p<0.01, Fig. 1, right panel). However, when removing the effect of velocity (using partial correlation test), the relationship between IdC and C was not significant (r=0.42, p=0.40).
DISCUSSION

Despite a previous case study by Morais et al. (2008), and a study that was conducted with sprint swimmers performing at incremental sub-maximal intensities (Komar et al., 2010), the present study is the first that aimed to relate IdC and C in front crawl. The present results agree with both the referred studies, finding positive and significant r values between both variables. In this study, however, it was confirmed that this is true for velocity values ranging from very low to heavy exercise intensities (~ VO2max).

All swimmers reached their maximal aerobic power during the incremental protocol, which was assured by traditional physiological criteria (cf. Fernandes et al., 2003). Subjects presented VO2max mean values similar to those described in the literature for experienced competitive swimmers (Wakayoshi et al., 1995; Rodriguez and Mader, 2003; Fernandes et al., 2006). The obtained mean values of [La]max are in accordance with the literature for intensities of exercise corresponding to VO2max (Fernandes et al., 2003; Rodriguez and Mader, 2003; Fernandes et al., 2006).

Along the incremental protocol it was observed that an increase in the swimming intensity led to an increase of the IdC. This is consistent with previous studies that showed a raise of IdC values with increasing race paces, namely from 1500/800 to 50 m freestyle (Chollet et al., 2000; Seifert et al., 2004; Seifert et al., 2007). This increase seems to be a strategy that swimmers use to overcome higher active drag that is related with higher swimming velocity (Seifert et al., 2004). These data also reveals that swimmers changed their arm stroke coordination, from moderate to heavy exercise intensities, in order to be able to reach higher swimming velocity. In fact, this shift in IdC from a catch-up pattern to a pattern closer to the opposition coordination mode, aiming to achieve higher propulsive continuity at VO2max swimming intensity, was also described before (Chollet et al., 2000; Seifert et al., 2004; Seifert et al., 2007). The values of IdC obtained in the present study were similar to those obtained in the previously mentioned studies and it did not reach positive values since IdC>0% only occurs after 93% of the swimmers maximal velocity, which corresponds to the 100 m maximal velocity (Seifert et al., 2004).

Such as the IdC, the C values also increased with velocity. This fact has been described before for front crawl stroke with similar C values (Zamparo et al., 2005; Morais et al., 2008; Komar et al., 2010), and seems to be justified by the increasing power output (P = Dv) necessary to overcome drag (D), and presumably by the increase in internal work associated with a higher stroke rate.

The main finding of this study was the very high direct relationship between IdC and C, which is, as stated, in accordance with previous studies in swimming, but also in human terrestrial locomotion, namely in the walk-run transition (cf. Seifert et al., 2007). Studies have been carried out in order to relate the C with other biomechanical parameters. Barbosa et al. (2008) showed that the C is highly related to stroke parameters, namely with stroke rate and stroke length, while Chollet et al. (1990) showed that C is dependent on swimming technique. In this sense, after observing that the IdC, a coordinative parameter, is strongly related with C, our results seems to be consistent with literature (Alberty et al., 2005), indicating that the mode of coordination might be an individual response to physiological constraints associated to the task. However, despite the agreement of the results of other approaches, the simple analysis of the r value obtained between IdC and C shows that the C increase with the increased continuity of technique (higher IdC), which seems to be paradoxical, being probably explainable by the fact that both parameters are strongly influenced by velocity (as shown in fig. 1). In accordance, we decided to analyse the partial correlation of the two variables removing the effect of velocity. Surprisingly, IdC and C did not correlate significantly (r=0.42, p=0.40). Furthermore, the obtained r value remains positive, while it was theoretically expected a negative relationship. Indeed, we hypothesised that, controlling the velocity effect, the reduction of propulsive discontinuities should allow the front crawl technique to become more economical, instead of implying higher energy costs. Samples with higher number of subjects as well as other factors (e.g. intracyclic velocity variation) should be searched to explain these apparently conflicting findings. Particularly, we recommend to study IdC and C at the same swimming velocity performed in different subjects, and in the same subjects manipulating coordination.

REFERENCES


Wakayoshi, K., D’Acquisto, L., Cappaert, J. & Troup, J. (1995). Relationship between oxygen uptake, stroke rate and swimming velocity performed in different subjects, and in the same subjects manipulating coordination.

ACKNOWLEDGEMENTS

This study was supported by grant: PTDC/DES/101224/2008
Evaluation of the Validity of Radar for Measuring Throwing Velocities in Water Polo

Ferragut, C.¹, Alcaraz, P.E.¹, Vila, H.¹, Abraldes, J.A.², Rodriguez, N.¹

¹Department of Sport Sciences, San Antonio Catholic University, Murcia, Spain
²Department of Sport Sciences, University of Murcia, San Javier (Murcia), Spain

Many studies have been published reporting measurements of velocity of balls, implements and corporal segments in sports where those skills are basic for performance. Skill in passing and throwing is vital in Water Polo because accuracy and the ability to produce high velocities are also valuable during the game for shots at goal. The aim of the present study was twofold; firstly to evaluate the validity of the radar gun measurements versus high velocity 2D photogrammetric analysis, in two different situation, and secondly, to establish a valid methodology to assess throwing velocity in Water Polo. The participants carried out 48 throws at maximum intensity from the penalty position (24 throws), and from an oblique position to the goal (θ ~ 20º) in the same penalty line (24 throws) with and without goalkeeper. They executed throws by alternating manner with a 3-min rest between each. The ball maximum velocity was measured with radar gun placed ten meters behind the goal, and aligned with the penalty line. Simultaneously; a 2D photogrammetric study was accomplished. The camera was mounted on a rigid tripod at a height of 1.0 m and placed at a distance of 10 m from the middle of the athlete’s lane. The optical axis of the camera was perpendicular to the direction of throwing for each different situation. One trial by each participant for each throw condition was analyzed. Pearson correlation coefficients were used to determine the interrelationship among the maximum velocity obtained by the radar gun and the 2D analysis. For frontal throws without goalkeeper the ICC was 0.96, and with goalkeeper was 0.84. Analyzing throws in oblique situation (θ ~ 20º), the ICC was 0.94 without goalkeeper and 0.96 with goalkeeper. All throws in the frontal situation showed a correlation coefficient of $r = 0.91$ and in the oblique position the correlation coefficient was $r = 0.94$ ($p ≤ 0.001$). In conclusion, the radar gun is a valid method to measure throwing velocity in water polo, both for frontal as well as for oblique throws.

Key words: Validity, Photogrammetric, 2D, radar gun, water polo throwing, water polo

INTRODUCTION

In the last decades, many studies have been published being interested in the measurement of velocity of balls, implements and corporal segments in sports where those skills are basic for performance. (DeRenne, Ho, & Blizbliu, 1990; Gorostiaga, Granados et al, 2005; Granados, Izquierdo et al, 2007; Lachowetz, Evon et al., 1998; McCluskey et al.; Skoufas, Stefanidis et al, 2003; Van den Tillaar & Ettema, 2004, Van den Tillaar & Ettema, 2007).

Skill in passing and throwing is vital in water polo because accuracy and the ability to produce high velocities are also valuable during the game for shots at goal. Two basic factors are of importance with regard to the efficiency of shots: accuracy and throwing velocity. Naturally, the faster the ball is thrown at the goal, the less time defenders and goalkeeper have to save the shot (Muijtjens, Joris et al, 1991). For these reasons, evaluating throwing velocity is an important issue for coaches in order to assess the training routines.

In order to measure throwing velocity different methodologies like high velocity cinematography have been used (Elliott & Armour, 1988; McCluskey et al.; Van den Tillaar & Ettema, 2004, Van den Tillaar & Ettema, 2007). This technique is knows to have high sensitivity, validity and reliability (Bartlett, 1997). However, this method is time consuming and is not suitable for use in the playfield. For these reasons, it is an unpractical method in order to provide fast feedback for coaches and athletes. Electronic timing gates is another way to assess throwing velocity (Gorostiaga, Granados et al, 2005; Granados, Izquierdo et al, 2007), but it is unpractical in water polo because of the playing medium (water).

In the last years, several studies have used radar guns as an alternative way to assess throwing velocity in team sports. This equipment has a lot of advantages, because we can assess throwing velocity without interfering in the playfield. Furthermore, velocities are measured instantaneously and in real competitive conditions. However, considering that radar gun calculates the objects velocities through the emission and reception of electromagnetic waves and its operation is based on Doppler’s principle, it is necessary validate the standardization protocols in order to avoid or at least to control the error range of the data obtained. For this reason, the protocol used in each study must be rigorous, especially in the radar gun positioning and it must be carefully applied in order to avoid obstacles between the object and the radar gun. The quality of the data is based on the rectilinear trajectories of the object. If the object does not achieve a rectilinear trajectory, it is uncertain to obtain valid data. Therefore, the aim of the present study was twofold; firstly to investigate the validity of the radar versus high velocity 2D photogrammetric analysis, in two different situations: throwing from the penalty position and throwing in oblique position to the goal (θ ~ 20º) in the same penalty line and secondly, to establish a valid methodology to assess throwing velocity in water polo.

METHODS

Two male water polo players were recruited for the study (35 ± 2 years old). The participants carried out 48 throws at maximum intensity from the penalty position (24 throws), and from an oblique position to the goal (θ ~ 20º) in the same penalty line (24 throws) with and without goalkeeper. Before beginning the measurements, the players performed a standardized warm up. They executed throws by alternating manner with a 3-min rest between each. An official water polo ball was used. The study was approved by the Human Subjects Ethics Committee of the San Antonio Catholic University of Murcia, the participants were informed of the protocol and procedures prior to their involvement and written consent to participate was obtained.

The ball maximum velocity was measured through the use of a radar gun (StalkerPro Inc., Plano, USA) with a frequency of 100 Hz and a sensitivity of 0.045 m·s⁻¹, placed ten meters behind the goal, and aligned with the penalty line.

Simultaneously, and with the aim of studying the reliability of the radar gun, a 2D photogrammetric study was accomplished. The shots were recorded using a digital mini DV video camera (Sony, HDR, HC9E, Japan) operating at 100 Hz. The camera was mounted on a rigid tripod at a height of 1.0 m and placed at a distance of 10 m from the middle of the athlete’s lane. The optical axis of the camera was perpendicular to the direction of throwing for each different situation, and the field of view of the camera was zoomed so that the ball was visible in a 10-m wide region. This field of view ensured that the maximum velocity of the ball would be recorded. The movement space was calibrated with two 2-m high poles that were placed along the midline of the athlete’s lane and 5 m apart. For 2D Analysis, The recommendations exposed by Bartlett were followed (Bartlett, 1997).

Kwon3D biomechanical analysis software (Visol, Cheolsan-dong, Korea) was used to analyze the video images of the trials. Two landmarks that defined a model of the ball were digitized in each image. Coordinate data were smoothed using a second-order Butterworth digital filter with a cut-off frequency of 6 Hz, and the velocity of the ball’s
centre of mass were calculated from the coordinate data using the finite differences method (Winter, 1990).

All digitizing was performed by the same operator in order to maximize the consistency of the dependent variables. The reliability of interparticipant digitizing and inter-participant digitizing was very high. An intraclass correlation coefficient (ICC) value of 0.999 was obtained when three instances of the same video sequence were digitized five times, and an ICC value of 0.998 was obtained when two researchers digitized three instances of the same sequence.

One trial by each participant for each throw condition was analyzed. After the throws were analyzed, Pearson correlation coefficients (SPSS 15.0, SPSS Inc, Chicago, USA) were used to determine the interrelationship among the maximum velocity obtained by the radar gun and the 2D analysis. The alpha level was set to \( p \leq 0.05 \).

RESULTS

The results obtained are presented in Table 1. Scientific community established that, when a high and statistically significant correlation coefficient between the instruments analyzed exists, we can say that they are valid enough. In the present study we found intraclass correlation coefficients higher (ICC) than 0.80 for all throwing situations and all of them reach statistical significance.

For frontal throws without goalkeeper the ICC was 0.96, and with goalkeeper was 0.84. If we analyze throws in oblique situation (\( \theta \approx 20^\circ \)), the ICC was 0.94 without goalkeeper and 0.96 with goalkeeper.

When we analyzed all throws in frontal situation the Pearson correlation coefficient obtained was 0.91 and in oblique position was 0.94.

Table 1. Pearson correlation coefficient between radar gun and photogrammetry instruments in different situations

<table>
<thead>
<tr>
<th>Variable</th>
<th>( V_{\text{radar}} \text{ (km·h}^{-1})</th>
<th>Mean ± SD</th>
<th>( V_{\text{video}} \text{ (km·h}^{-1})</th>
<th>ICC</th>
<th>( \rho )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal without goalkeeper</td>
<td>51.3 ± 6.8</td>
<td>51.8 ± 6.7</td>
<td>0.958</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Frontal with goalkeeper</td>
<td>51.3 ± 3.2</td>
<td>50.2 ± 4.2</td>
<td>0.840</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Oblique without goalkeeper</td>
<td>50.8 ± 3.7</td>
<td>49.9 ± 4.7</td>
<td>0.939</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Oblique with goalkeeper</td>
<td>49.3 ± 5.6</td>
<td>49.4 ± 5.7</td>
<td>0.965</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Frontal (n=24)</td>
<td>51.3 ± 5.1</td>
<td>51.0 ± 5.5</td>
<td>0.911</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Oblique (n=24)</td>
<td>50.0 ± 4.7</td>
<td>49.7 ± 5.1</td>
<td>0.941</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Total (n=48)</td>
<td>50.6 ± 4.9</td>
<td>50.3 ± 5.2</td>
<td>0.927</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

DISCUSSION

The main goal of this study is to validate the radar gun as valid instrument to measure throwing velocities in water polo.

This is a very important issue, because skills in passing and throwing the ball are vital in water polo for reasons of accuracy and ability to produce high velocities, which are valuable during the game. In water polo, the overhead throw is the most effective and frequently used to propel the ball and to score goals (Bloomfield, Blanksky et al, 1990). The overhead throw accounts for up to 90% of all passes and shots during a game. In this pattern, the ball comes from behind the body and is brought up over the head and released in front of the body. The goal of the overhead throw is to achieve high endpoint velocity (Bloomfield, Blanksky et al, 1990). Naturally, the faster the ball is thrown at the goal, the less time defenders and goalkeeper have to save the shot (Muijtjens, Joris et al, 1991).

For this reason measuring throwing velocity during training sessions and during real competition match is an important issue for coaches and athletes. But unfortunately, these measures are really complicated because of the water. The radar gun solves the problems mentioned, because we can obtain the results of the measures immediately, we can assess throwing velocity without getting inside the playfield and we can measure throwing velocity in a real match. Now it is possible to use the radar gun as a valid method for measure throwing velocity even in oblique throw situations in water polo.

CONCLUSION

The results suggest that the measurements obtained with radar are valid, both for frontal throws (\( r=0.911, p=0.000 \)) as well as for oblique throws (\( r=0.941, p=0.000 \) (0 – 20º), with and without goalkeeper.

The radar gun is a valid method to measure throwing velocity during a water polo training session and during a water polo match, so for frontal throws as well for oblique throws (\( r=0.91, p=0.000 \)).

REFERENCES


ACKNOWLEDGEMENTS

The authors would like to acknowledge funding support from Spanish Government grant DEP 2008-06114-I+D (BOE 20 Nov 2007), and to Francisco Argudo Iruritaga for his support during the measurements.
Biophysical Analysis of the 200m Front Crawl Swimming: a Case Study

Figueiredo, P.; Sousa, A.; Gonçalves, P.; Pereira, S.M.; Soares, S.; Vilas-Boas, J.P.; Fernandes, R.J.

1University of Porto, Faculty of Sport, CIFI2D
2Federal University of Santa Catarina, Santa Catarina, Brazil

The performance of a swimmer during 200 m front crawl swim was analysed, integrating coordinate, biomechanical, electrophysiological and bioenergetical data. One male swimmer (participant at the 2008 Olympic Games and national record holder) swam 200m for the assessment of the intracyclic velocity variation (IVV) in x, y and z axes, arm coordination, oxygen uptake and neuromuscular activity. Afterwards, the swimmer performed 50, 100 and 150 m at the 200 m pace for blood lactate kinetics analysis. This study highlighted the stability of the IVVs, continuity of arm coordination in the last 100 m. The electromyography data evidenced a significant fatigue involvement. Moreover, oxygen consumption rate values decreased as blood lactate concentrations rate and absolute values increased along the effort.

Key words: EMG, Intracyclic velocity variation, Arm coordination, Energy expenditure, Biophysics.

INTRODUCTION

Propulsive and drag forces acting on the swimmer’s body are major performance determinants, being affected by technique, motor organisation and control. However, muscular activity, as well as energy expenditure of exercise, is considered as swimming influencing parameters (Clarys and Cabri, 1993; Fernandes et al., 2006). In this sense, to understand the real involvement of the above parameters in swimming, a biophysical approach is needed (Pendergast et al., 2006), combining data from different areas. The 200 m front crawl is dependent on both anaerobic and aerobic energy systems, implying higher levels of fatigue (Costill et al., 1992). However, the interactions between the performance influencing factors in this specific event were not yet discussed.

The aim of the present study was to analyse the 200 m front crawl maximal effort, performed by an elite Olympic swimmer, assessing the intracyclic velocity variation of the centre of mass, arm coordination, energy expenditure and neuromuscular activity.

METHODS

A male swimmer, 2008 Olympic Games participant and 200m front crawl national record holder (21 years old, 71kg of body mass, 180cm of height, 182cm of arm span and 8.8% of body fat mass) volunteered to participate in the present study. The test session took place in a 25 m indoor swimming pool.

Briefly, the subject, after a moderate intensity individual warm-up, performed a 200 m front crawl test at maximal intensity (as in competition), with push-in-water start. The swimmer was monitored when passing through a specific pre-calibrated space with dimensions of 3x1.5x3m for the horizontal (x), vertical (y) and lateral (z) directions. Thirty points of calibration were used, and the synchronisation of the images was obtained using a pair of lights observable in the field of view of each one of the six video cameras (Sony® DCR-HC42E, Japan). The angle between the optical axes of the two surface cameras was approximately 120°, while the angles between the optical axes of adjacent underwater cameras varied from 75° to 110°. Two complete arm stroke cycles, without breathing, for each 50m of the 200m front crawl were digitised using the APASystem (Ariel Dynamics, USA) at a frequency of 50 Hz, manually and frame by frame. Zatsiorsky and Seluyanov’s model, adapted by de Leva (1996) was used to analyse the kinematic data. Twenty-one body landmarks were digitised in each frame to represent the endpoints of the head, torso, upper arms, forearms, hands, thighs, shanks and feet. Direct Linear Transformation algorithm was used for three-dimensional reconstruction, as well as a 6 Hz low pass digital filter for the smoothing of the data. The velocity (v) was calculated by dividing the displacement of centre of mass (CM) in one stroke cycle for its total duration. Additionally, stroke rate (SR) was assessed through the inverse of its time duration, and stroke length (SL) was determined through the horizontal displacement of the CM during a stroke cycle.

To analyse the intracyclic velocity variation (IVV) for the x, y and z axes of the CM, was calculated through the coefficient of variation of the \( v_0 \) distribution.

Arm movement was broken into four phases (entry/catch, pull, push and recovery) (Chollet et al., 2000), using the above-referred digitised model. The duration of the propulsive phase was considered to be the sum of the pull and push phases, and the duration of the non-propulsive phase the sum of the entry/catch and recovery phases. Arm coordination was quantified using the Index of Coordination (IDC) proposed by Chollet et al. (2000), measuring the lag time between the propulsive phases. The IDC was calculated for two complete arm strokes per 50m, and expressed as a percentage of complete arm stroke duration.

For the total energy expenditure ([E] assessment, oxygen uptake (VO\(_2\)) was recorded breath-by-breath by the K4b\(^2\) telemetric gas exchange system (Cosmed, Roma, Italy), during the 200m front crawl exercise. Artefacts were manually eliminated and data were averaged every 5 s (cf. Sousa et al., in press). After 90 min of rest interval, the swimmer performed a 50m front crawl test to assess blood lactate concentration ([La\(_{-}\)]), at the same swimming v as the previous 200m (controlled by a visual light pacer – TAR 1.1, GBK Electronics, Aveiro, Portugal – with a flash every 5m). Twenty-four hours later, the swimmer performed 150m and 100m, with 90 min interval between tests, in order to simulate as much as possible the 200m test conditions, also using a respiratory snorkel and valve system. Capillary blood samples (5μl) were collected from the ear lobe, at rest, as well as at 1, 3, 5, and 7 min of recovery, to assess rest and post exercise [La\(_{-}\)] (Lactate Pro, Arkray, Inc.). It was ensured, by measuring, that swimmer had similar blood lactate concentration rest values prior to each test.

The [E] corrected for body mass was calculated using the VO\(_2\) net (difference between the average value of each 50m length and the rest value), and the blood lactate net (difference between the value measured in two consecutive lengths), transformed into VO\(_2\) equivalents using a 2.7 mO\(_2\)kg\(^{-1}\).mmol\(^{-1}\) constant (di Prampero et al., 1978). Anaerobic lactate energy sources were assumed to be negligible in this type of effort (Rodriguez and Mader 2003).

For the muscular analysis active differential surface electromyography (EMG) recordings were used of the flexor carpi radialis, biceps brachii, triceps brachii, pectoralis major, upper trapezius, rectus femoris, bicep femoris and tibialis anterior muscles during the 200m front crawl. These muscles were selected according to their main function and anatomical localisation, being considered important in front crawl swimming (Figueiredo et al., 2009). The skin of the swimmer was shaved and rubbed with an alcohol solution. Silver/silver chloride circular surface electrodes, with preamplifiers (An AD621 BN), were placed in a bipolar configuration with 2.0 cm inter-electrodes distance, in line with the muscle’s fibre orientation. Electrodes were placed in the midpoint of the contracted muscle belly as suggested by Clarys and Cabri (1993), and covered with an adhesive bandage ( Opsite Flexifix) to avoid contact with water (Figueiredo et al., 2009). A reference electrode was attached to the patella. The total gain of the amplifier was set at 1100, with a common mode rejection ratio of 110 dB. Additionally, the swimmer used a complete swimsuit, in order to reduce the mobility of the electrodes and to increase the comfort of the swimmer, allowing normal motion.

The EMG signals were recorded at a sampling frequency of 1000 Hz with a 16-bit resolution and then converted by an analogical/digital converter (BIOPAC System, Inc). To synchronise EMG and video, an electronic flashlight signal / electronic trigger was marked simultane-
ously on the video and EMG recordings. The EMG data analysis was performed using the MATLAB 2008a software environment (MathWorks Inc., Natick, Massachusetts, USA). A new highly sensitive spectral index (FINSmk), proposed by Dimitrov et al. (2006), was calculated for one stroke cycle for each 25m. The FINSmk has been proposed to overcome the relatively low sensitivity of the median frequency and the mean frequency. The FINSmk indices were calculated as the ratio between the spectral moments of order (-1) and order, k:

\[ F_{\text{INSmk}} = \frac{\int f^2 f^{-1} . P S(f) . df}{\int f^2 f^{-k} . P S(f) . df} \] (1)

where k was 5, PS(f) was the spectral power for the currency frequency f and f1 = 8 Hz and f2 = 500 Hz were the high and low-pass frequencies of the amplifier filter. The relative changes in values of the spectral index, for different repetitions were calculated against the first repetition of the corresponding set: for instance, FINSmk/FINSmk x 100, % (n = 1, 2, ..., 8 lap number).

Linear regression analysis method was performed on muscle EMG parameters (laps 1-8). The regression line gradients were analysed to compare rate of change and, hence, rate of fatigue development. The level of significance for all statistical tests was set at p < 0.05.

RESULTS

In Figure 1 it is possible to observe the decay of \( v \), SL and SR through the 200 m front crawl with a slightly increasing of the SR in the last length.

Values for IVV (x, y and z) and coordinative organisation parameters (IdC and stroke phases) are presented in fig. 2 (left panel and right panel, respectively) for the four laps of the 200m front crawl test.

![Figure 1. General biomechanical parameters (v, SL and SR) values during the 200m front crawl effort.](image1)

![Figure 2. Values for intracyclic velocity variation (IVV) in x, y and z axes (left panel) and values of velocity (v), stroke rate (SR), stroke length (SL), index of coordination (IdC), entry/catch, pull, push, recovery, propulsive phase and non-propulsive phase in the four laps of the 200m front crawl.](image2)

Figure 3. \( \dot{E} \), VO2 and \([La^-]\) kinetics during the 200m front crawl effort. The VO2 figure was averaged every 10s for graphical proposes (upper panel) and linear regression analysis of the relative changes of spectral index FINSmk (lower panel).
DISCUSSION

The kinetics of the stroking parameters (SL and SR) along the 200m is in agreement with the literature (Alberty et al., 2005). Moreover, the decrease of v along the test can be explained by different SR and SL combinations, as previously reported (Huot-Marchand, et al., 2005). The decrease of the SL values could be linked to the development of local muscular fatigue, reflecting a declining capacity to deliver power output. In addition, the swimmer tried to increase SR in order to compensate the SL decrease.

The observed stability of IVVx and the larger magnitudes of IVV found for y and z than in x axis, are in agreement with the literature (Psycharakis et al., 2010). This IVVs stability suggests a coordinative adaptation of the upper limbs, as Figueiredo et al. (2009) reported no relationship between IVV and IdC in x, y and x axes during the 200 m front crawl effort. The coordinative adaptation pattern might be explained by the swimmer's inability to minimise the resistive force as the arm coordination change (increasing the values of IdC) mostly in the last 50m of the 200m front crawl (Alberty et al., 2005; Figueiredo et al, in press), however IdC maintained in catch-up mode (<0%) during the whole effort. This possibly reflects a longer duration of the stroke cycle propulsive phase and not necessarily higher force production, as the v and SL decreased in the last 50m of the 200m.

The Ė increased in the first 50 m, resulting from an exponential increase of the VO₂ kinetics at the beginning of exercise (cf. Fernandes et al., in press), reaching the VO₂ peak in the second 50 m. In the 3rd lap the swimmer was not able to maintain the high VO₂ values, reducing the v, although maintaining [La ]. Afterwards, in fourth 50 m, the glycolytic contribution was higher, which lead to high values of Ė. The inability to maintain swimming v in the last laps of the 200m effort was coincident with the increase of the fatigue indices for the muscles studied (except for the tibialis anterior). These indices (cf. Dimitrov et al., 2006) were assessed as the ratio between the signal spectral moment of order (-1), to emphasise the increase in low and ultra-low frequencies in the EMG spectrum attributable to the increase of negative after-potentials, expressing muscular fatigue. Indices were normalised to spectral moment of order (5), which emphasised the effect of decreases in the high frequencies, attributable to the increased duration of the intracellular action potentials and the decreased action potential propagation velocity.

CONCLUSION

This study highlights the interaction between coordinative, biomechanical, electromyographical, and bioenergetical performance influencing parameters. Changes in some factors could imply other modifications or offer the stability needed for a better performance. The importance of observing from a biophysical point of view was shown, as the increasing of performance needs an intervention in a large number of parameters that can influence positively or negatively this process.

REFERENCES


ACKNOWLEDGMENTS

The first author acknowledges the Portuguese Science and Technology Foundation for his PhD grant (SFRH / BD / 38462 / 2007). This study was supported by grant: PTDC/DES/101224/2008
Measuring Active Drag within the Different Phases of Front Crawl Swimming

Formosa, D. P.\textsuperscript{1,2} Mason, B. R.\textsuperscript{1} & Burkett, B. J.\textsuperscript{2}

\textsuperscript{1} Australian Institute of Sport, Australia
\textsuperscript{2} University of the Sunshine Coast, Australia

The aim of this study was to quantify the passive and active drag forces in front crawl swimming at the swimmer’s maximum swimming velocity and to present this data as a force-time profile. This method enabled the minimum and maximum force with respect to the phase within the stroke to be identified. Elite freestylers (n=18) completed three maximum swim velocity time trials to determine their maximum velocity. This was followed by three passive drag trials and three active drag trials using a towing device mounted upon a force platform. The computed active drag and the propulsive force profiles were represented as a force-time graph, allowing identification of intra-cyclic force fluctuations. The force-profiles were synchronised to video footage which provided unique quantitative stroke mechanic feedback to the elite coaches and athletes.

KEYWORDS: biomechanics, swimming, front crawl, active drag, technique

INTRODUCTION

An elite swimmer’s success during the free swimming phase is primarily dependent upon their ability to minimise active drag, whilst optimising propulsive force. Active drag is defined as the water resistance associated with the swimming motion (Kolmogorov et al., 1997). Before 1974 passive drag, defined as the amount of water resistance that a human body experiences in an unchanging body position, was considered the best method of predicting active drag (Chatard et al., 1990). In the late 1980s, a research team in the Netherlands developed the first system to measure active drag, known as the MAD system. The MAD system required the participant to swim at a constant velocity, whilst pressing upon fixed pads with the hands. The swimmer’s legs were elevated and restricted with pull buoy. This system was limited to front crawl only. Kolmogorov & Duplischeva (1992) developed the Velocity Perturbation Method (VPM) which measured active drag irrespective of swimming stroke. Using the VPM method participants were instructed to swim maximally under two conditions; without and with a hydrodynamic body. The hydrodynamic body was of a known resistance, therefore allowing active drag to be determined by the velocity differences between the two conditions. The common assumption made in calculating active drag was that at a constant velocity the propulsive force was equal to the opposing active drag (Kolmogorov & Duplischeva, 1992; Toussaint et al., 2004). Regardless of the method adopted, active drag was calculated as a mean value, therefore ignoring the fluctuations in the propulsive force during the stroke phases. The swimming stroke is typically segmented into distinct phases consisting of the entry and catch, pull, push and recovery (Chollet et al., 2000). The primary aim of this study was to quantify the passive and active drag values as a force-time profile by using a motorised towing device. The secondary aim of this study was to examine the force-time profile to determine in which segment of the stroke phase a swimmer produced minimum and maximum force, and therefore providing unique biomechanical feedback to elite coaches and athletes.

METHODS

Following human ethics approval by the University of the Sunshine Coast and the Australian Institute of Sport, eighteen Australian national front crawl swimmers (10 male aged 21 ± 2.2 years, 8 female aged 20 ± 3.0 years) were tested to determine the participant’s passive and active drag profile.

Firstly, the swimmers completed a typical 20 min individual race preparation warm up, followed by three individual maximum swimming velocity trials. The maximum velocity trials were measured over a 10 m interval using two 50 Hz cameras (Samsung model: SCC-C4301P). The cameras were time coded. Using a custom computer program, the mean velocity was calculated for each trial. The trial with the highest mean velocity was selected for the passive and active drag trials. The passive and active drag testing was conducted using a motorised towing device, which enabled a constant towing velocity to be accurately set. The towing device was positioned directly upon a calibrated Kistler\textsuperscript{TM} force platform (Kistler Instruments in Winterthur Switzerland Dimensions: 900 x 600 m Type Z12697). The towing device and the force plate enabled the force required to tow the swimmer through the water to be measured. The validity and reliability of the system was determined prior to data collection. During the three passive drag trials the swimmers were towed at their maximum swimming velocity. The swimmers were instructed to hold the end of the tow line around the middle finger of their dominant hand, with the non-dominant hand interlocking to minimise any additional movement. The criteria for a successful passive trial was that the swimmer maintained a streamline position just below the water surface, with no arm strokes nor kicking nor breathing, and there was visible water flow passing over the head, back and feet. Three active drag trials were completed at a velocity five percent greater than the swimmer’s maximum swimming velocity. The active drag trials consisted of the participants actively swimming whilst using their typical stroke characteristics with an Eyeline\textsuperscript{®} tow belt attached to the lumbar region and the dynamometer. Through pilot testing the five percent increase in towing velocity was considered to not have any major effect on the swimmer’s stroke pattern while still allowing continuous force measurement.

Data capture was collected for a total of seven seconds, one second prior to and six seconds after the synchronisation trigger was depressed. The sensitivity of the amplifier was set at 5000 pC for both conditions. Data was processed using a 12 bit A to D card, sampled at 500 Hz, and a 5 Hz Butterworth low pass digital filter was applied to the force data collected (Formosa et al., 2009). Each trial was video-recorded at 50 Hz using three genlocked cameras; a side-on underwater, side-on above and head-on camera. The side-on underwater and side-on above water cameras were synchronised with an Edirol video mixer (EDI-V8).

The following formulas were used to determine active drag:

\[
F_a = 0.5C \cdot \rho \cdot A \cdot V^2
\]

Where \( C \) is the constant, \( \rho \) is a water density, \( A \) is the frontal surface area of the swimmer & \( V \) is the force needed to pull the swimmer at the increased velocity, which was measured by the force platform. \( F_1 \) is force applied by the swimmer during free swimming (unaided) and is assumed to be equal to the total drag force during free swimming. \( F_2 \) is the force applied by the swimmer during free swimming in the assisted condition.

Here it was assumed an equal power output in both the free swimming and the active drag swimming conditions existed:

\[
F_1 \approx F_2
\]

If \( F_1 \approx F_2 \) and therefore \( F_1 \cdot V_1 = F_2 \cdot V_2 \), substitution of \( F_2 \) and \( F_1 \) gives:

\[
0.5C \cdot \rho \cdot A \cdot V_1^2 = 0.5C \cdot \rho \cdot A \cdot V_2^2 - F_1 \cdot V_1
\]

Rearranging the formula to find \( C \):

\[
C = \frac{F_1 \cdot V_1}{0.5 \rho \cdot A \cdot (V_1^2 - V_2^2)}
\]

substitution of \( C \) gives the following formula for active drag:

\[
F_a = \frac{F_1 \cdot V_1}{V_2} - \frac{F_1}{V_2}
\]

Z12697). The towing device and the force plate enabled the force required to tow the swimmer through the water to be measured. The validity and reliability of the system was determined prior to data collection. During the three passive drag trials the swimmers were towed at their maximum swimming velocity. The swimmers were instructed to hold the end of the tow line around the middle finger of their dominant hand, with the non-dominant hand interlocking to minimise any additional movement. The criteria for a successful passive trial was that the swimmer maintained a streamline position just below the water surface, with no arm strokes nor kicking nor breathing, and there was visible water flow passing over the head, back and feet. Three active drag trials were completed at a velocity five percent greater than the swimmer’s maximum swimming velocity. The active drag trials consisted of the participants actively swimming whilst using their typical stroke characteristics with an Eyeline\textsuperscript{®} tow belt attached to the lumbar region and the dynamometer. Through pilot testing the five percent increase in towing velocity was considered to not have any major effect on the swimmer’s stroke pattern while still allowing continuous force measurement.

Data capture was collected for a total of seven seconds, one second prior to and six seconds after the synchronisation trigger was depressed. The sensitivity of the amplifier was set at 5000 pC for both conditions. Data was processed using a 12 bit A to D card, sampled at 500 Hz, and a 5 Hz Butterworth low pass digital filter was applied to the force data collected (Formosa et al., 2009). Each trial was video-recorded at 50 Hz using three genlocked cameras; a side-on underwater, side-on above and head-on camera. The side-on underwater and side-on above water cameras were synchronised with an Edirol video mixer (EDI-V8).

The following formulas were used to determine active drag:

\[
F_a = 0.5C \cdot \rho \cdot A \cdot V^2
\]

Where \( C \) is the constant, \( \rho \) is a water density, \( A \) is the frontal surface area of the swimmer & \( V \) is the force needed to pull the swimmer at the increased velocity, which was measured by the force platform. \( F_1 \) is force applied by the swimmer during free swimming (unaided) and is assumed to be equal to the total drag force during free swimming. \( F_2 \) is the force applied by the swimmer during free swimming in the assisted condition.

Here it was assumed an equal power output in both the free swimming and the active drag swimming conditions existed:

\[
F_1 \approx F_2
\]

If \( F_1 \approx F_2 \) and therefore \( F_1 \cdot V_1 = F_2 \cdot V_2 \), substitution of \( F_1 \) and \( F_2 \) gives:

\[
0.5C \cdot \rho \cdot A \cdot V_1^2 = 0.5C \cdot \rho \cdot A \cdot V_2^2 - F_1 \cdot V_1
\]

Rearranging the formula to find \( C \):

\[
C = \frac{F_1 \cdot V_1}{0.5 \rho \cdot A \cdot (V_1^2 - V_2^2)}
\]

substitution of \( C \) gives the following formula for active drag:

\[
F_a = \frac{F_1 \cdot V_1}{V_2} - \frac{F_1}{V_2}
\]
$V_r$ is the swimmer's free swim maximum velocity and $V_f = 5\%$ greater than the swimmer's free swim maximum velocity (Kolmogorov & Duplischcheva, 1992) (Note: equation was modified for assisted, rather than resisted). To identify the force distribution within the stroke cycle, phases were considered as entry and catch, pull, push and recovery (Chollet et al., 2000).

RESULTS

The coefficient of variation between the towing device velocity and the side-on cameras was 0.6 % (90% Confidence Intervals (CI) 0.5 to 0.7). The Pearson product moment coefficient between the towing device pulling velocity and the calculated side-on camera velocity was $r = 1.0$. Within a testing day the typical error of measurement from the force platform set up was 4.0 N (90% CI 3.4 to 4.8) or 5.2% (4.4 to 6.3) for passive drag; and 2.5 N (2.1 to 3.0) or 4.9% (4.1 to 5.9) for the active drag. Testing sessions within and between days of testing, reported intraclass correlation coefficients (ICCs) of between 0.97 (0.93 to 0.99) and 0.99 (0.96 to 1.00) for passive and active drag respectively.

The mean passive drag value for the male participants was 78.9 ± 1.6 N at a mean velocity of 1.89 m·s⁻¹, whilst the mean passive drag value for the female participants was 49.7 ± 1.8 N at a mean velocity of 1.72 m·s⁻¹. The mean active drag value for the male participants was 228.4 ± 10.8 N at a maximum velocity of 1.89 m·s⁻¹, compared to the female mean value of 164.4 ± 11.7 N, at a maximum velocity of 1.72 m·s⁻¹.

The mean passive drag value for the male participants was 78.9 ± 1.6 N at a mean velocity of 1.89 m·s⁻¹, whilst the mean passive drag value for the female participants was 49.7 ± 1.8 N at a mean velocity of 1.72 m·s⁻¹. The mean active drag value for the male participants was 228.4 ± 10.8 N at a maximum velocity of 1.89 m·s⁻¹, compared to the female mean value of 164.4 ± 11.7 N, at a maximum velocity of 1.72 m·s⁻¹.

The mean passive drag value for the male participants was 78.9 ± 1.6 N at a mean velocity of 1.89 m·s⁻¹, whilst the mean passive drag value for the female participants was 49.7 ± 1.8 N at a mean velocity of 1.72 m·s⁻¹. The mean active drag value for the male participants was 228.4 ± 10.8 N at a maximum velocity of 1.89 m·s⁻¹, compared to the female mean value of 164.4 ± 11.7 N, at a maximum velocity of 1.72 m·s⁻¹.

The mean passive drag value for the male participants was 78.9 ± 1.6 N at a mean velocity of 1.89 m·s⁻¹, whilst the mean passive drag value for the female participants was 49.7 ± 1.8 N at a mean velocity of 1.72 m·s⁻¹. The mean active drag value for the male participants was 228.4 ± 10.8 N at a maximum velocity of 1.89 m·s⁻¹, compared to the female mean value of 164.4 ± 11.7 N, at a maximum velocity of 1.72 m·s⁻¹.

The mean passive drag value for the male participants was 78.9 ± 1.6 N at a mean velocity of 1.89 m·s⁻¹, whilst the mean passive drag value for the female participants was 49.7 ± 1.8 N at a mean velocity of 1.72 m·s⁻¹. The mean active drag value for the male participants was 228.4 ± 10.8 N at a maximum velocity of 1.89 m·s⁻¹, compared to the female mean value of 164.4 ± 11.7 N, at a maximum velocity of 1.72 m·s⁻¹.

The mean passive drag value for the male participants was 78.9 ± 1.6 N at a mean velocity of 1.89 m·s⁻¹, whilst the mean passive drag value for the female participants was 49.7 ± 1.8 N at a mean velocity of 1.72 m·s⁻¹. The mean active drag value for the male participants was 228.4 ± 10.8 N at a maximum velocity of 1.89 m·s⁻¹, compared to the female mean value of 164.4 ± 11.7 N, at a maximum velocity of 1.72 m·s⁻¹.

The mean passive drag value for the male participants was 78.9 ± 1.6 N at a mean velocity of 1.89 m·s⁻¹, whilst the mean passive drag value for the female participants was 49.7 ± 1.8 N at a mean velocity of 1.72 m·s⁻¹. The mean active drag value for the male participants was 228.4 ± 10.8 N at a maximum velocity of 1.89 m·s⁻¹, compared to the female mean value of 164.4 ± 11.7 N, at a maximum velocity of 1.72 m·s⁻¹.

Figure 1: Male participant nine propulsive force profile at 1.84 m·s⁻¹. 1. L entry R push 2, L recovery, L pull 3, L push R entry 4. L recovery, R pull (Chollet et al., 2000).

Figure 2: Male participant ten propulsive force profile at 1.81 m·s⁻¹. 1. R entry L push 2. L recovery, R pull 3. R push L entry 4. R recovery, L pull (Chollet et al., 2000).

DISCUSSION

The aim of this study was to quantify active drag during freestyle swimming, whilst providing a valuable biomechanical feedback tool for elite coaches and athletes. The mean passive drag values measured were comparable to those previously reported, such as the force values of 53.3 ± 7.2 N at 1.76 m·s⁻¹ for female participants (Maglischo et al., 1988). Similarly, Kolmogorov & Duplischcheva (1992) observed male and female passive values ranging from 69.7 – 103.0 N and 44.2 – 56.9 N, respectively at velocities 1.73 – 1.91 m·s⁻¹ and 1.52 – 1.67 m·s⁻¹, respectively.

The active drag obtained in this study does not concur with the literature. Toussaint et al. (2004) compared active drag values collected with both the MAD and VPM systems. Active drag measured at a velocity of 1.64 m·s⁻¹ was 66.9 N (MAD) and 53.2 N (VPM). Similar findings were reported by Toussaint et al. (1988) when comparing active drag of females and males. Using the function $\text{D} = \text{Av}^2$ to obtain a range of values from the MAD system, the researchers were able to make a comparison with the mean results from the present study. The values measured using the MAD system were 70.2 N at a maximum velocity of 1.72 m·s⁻¹ (females), whilst for males, the maximum velocity was 1.89 m·s⁻¹ with an active drag of 111.4 N. This variation between the results may be due to the different methods used to assess active drag. The MAD system was limited to arm propulsion only, whilst the VPM system measured the whole body whilst in a resisted state.

Representing active drag in a force–time graph synchronised to video footage allowed researchers and coaches to identify the propulsive force fluctuations within the stroke phases. As illustrated in figures 1 and 2, there is a limited number of researchers that have explored the propulsive force production throughout different stroke phases of front crawl, however most researchers have examined this through digitising. There was significant variation between minimum and maximum propulsive force range for left and right stroke phases between and within participants. By examining the force–time graph synchronised to video footage this allowed researchers to identify during which exact phase, minimum and maximum force production occurred. It was evident that mean minimum propulsive force was generated during the first pull phase of the stroke cycle. The towing device used to calculate active drag, measured the whole body propulsive action. This considered the effect the recover arm had on the total body propulsive force. This did not indicate the pull phase was not generating propulsive force, however the arm producing the pulling motion was counteracting the equal and opposing forces of the recovering arm. The force–time graph indicated that the maximum propulsive force production occurred during the final push phases of the stroke cycle. Previous researchers have adopted an indirect method to determine the forces associated with the hands/arms (Maglischo et al., 1988; Schleihaufl, 1979). These researchers digitised the hand/arm motion to determine the lift and drag components. The researchers reported maximum propulsive force during the final push phase. In the present study, examining the force–time graph synchronised to video footage, it was evident that maximum propulsive force was unable to be produced until the recovering arm was in the water following the catch.

CONCLUSION

The present study demonstrated the importance of representing active drag as instantaneous force, rather than a mean value. This provided unique and valuable insight into the intra-cyclic force fluctuations with-
in a stroke cycle. The graphical demonstration allowed comparison for future intervention studies. The values measured from the towing device were comparable to previous research during the passive drag condition. However the active drag values were much greater than previously investigated. Through examining the force-time graph synchronised to video footage, it was evident that minimum force was produced during the pull phase and maximum force during the push phase. The towing device used to calculate active drag, measured the whole body propulsive action, therefore taking into consideration the effect the recover arm had on the total body propulsive force.

REFERENCES

ACKNOWLEDGMENTS
The researchers would like to thank the Australian Institute of Sport, Aquatics Testing, Training and research, Australian and National swimming team for their contribution to the research.

The Mechanical Power Output in Water Polo Game: a Case Report
Gatta, G., Fantozzi, S., Cortesi, M., Patti, F., Bonifazi, M.

1Faculty of Exercise and Sport Science, University of Bologna, Italy
2Computer Sciences and Systems, Bologna, Italy
3Faculty of Medicine, University of Siena, Italy
4Italian Swimming Federation, Roma, Italy

In water polo some authors have assessed the physical requirements of the game by analysing physiological indices or considering the distances covered at various swimming speeds in the match. In this work, the passive drag was measured in “best glide” (Swim) and “head-up” (Wp) position in a water polo player. The active drag was estimated indirectly from the passive drag. The mechanical power required to play a match is calculated on the data of a match model obtained from a video analysis in a series of international water polo matches. The average mechanical power of a water polo match in the Swim model was 150.489 J/2400 s = 62.70 W, while in WP model it was 481.375 J/2400 s = 200.57 W. The mechanical power required in water polo players could be more than three-fold higher than that required for freestyle swimming at the same velocities.

KEYWORDS: water polo, mechanical power, drag, acceleration, trudgen

INTRODUCTION
A precise definition of the performance model in sports games is far from being simple. In water polo some authors have assessed the physical requirements of the match by analysing physiological indices as heart rate or considering the distances covered at various swimming speeds in a series of matches (Pinnington et al. 1987, Hohmann & Frase 1992, Rudic et al. 1999, Platanou & Geladas 2006). Coaches still develop training programs considering swimming speeds but this does not take into account that, during the match, the water polo player does not move as a swimmer in the best hydrodynamic position, but: 1) swims with the head raised and often in contact with opponents, therefore not totally in a hydrodynamic position that is subjected to a higher drag; 2) starts statically in maximum acceleration, without any push from a fixed support. For this reason we believe that motion patterns of swimming used so far underestimate the real amount of mechanical power developed by the player during the match.

The purpose of this work was to compare, in a water polo player, the mechanical power required to play a match as computed with two different methods: the method used so far in swimming, and a new model based on the specific analysis of the technique of water polo.

METHODS
To obtain the power required to swim at different speeds, the resistive force of the water must be computed, defined by the value of the drag. The estimation of active drag is still quite complex and the methods used do not find an agreement among scientists, while the measurement of passive drag is easier, and more reliable. In a water polo player (27 years, 1.77 m, 79 kg), two indices of passive drag (pd) were measured with the method of towing at different speeds. The first index was obtained in the position of “best glide” (Swim), i.e. a lying down position with head between the arms, while the second index was obtained in a “head-up” position, similar to the previous one, but with head above water, common in water polo playing (Wp).

For the test we used a tow electromechanical motor (Ben-Hur, ApLab, Roma) dragging the swimmer through a cable at a programmed speed, while assessing the resistance of the fluid (see figure 1).
Trials were carried out at increasing speeds (1.2-1.4-1.6-1.8-2 m/sec) and the curves of the equation:

\[ D = k \cdot V^n \]  (1)

(\( D = \) drag, \( k = \) drag coefficient, \( V = \) swimming velocity, \( n = \) exponent velocity) were graphically assessed (Bonifazi et al. 2005). From the formulas obtained, the active drag in the two conditions was estimated (Kjendlie & Stallmann 2008), as 1.5 times (a) the value of passive drag. This estimate was performed to compute the work, but it does not affect the comparison between the two models under examination. Furthermore, the power required during acceleration was estimated. In these cases the resistance is even greater than normally due to the effect of the "added mass" of water next to the swimmer. First of all, the maximum acceleration reached by the typical water polo starting in "trudgeon" was computed deriving the speed signal (expressed in m/s) given as output from the speed encoder. Then, the drag in acceleration from static starting (Wp acceleration = WpA) was obtained by the tow Ben Hur, while it provided an acceleration at the swimmer equal to the maximum acceleration computed by the speed encoder.

From the previously obtained drag force formulas, the value of the mechanical power required to the water polo player was computed multiplying the drag by speed:

\[ \text{Power-drag (Pd)} = D \cdot v \]  (2)

It is also possible to write:

\[ Pd = k \cdot v^n \cdot v \]  (b)  (3)

These values were applied to the model of an international match (Rudic et al. 1999). The match model is obtained from the individual analysis of distances and velocities in the Rome 1994 World Championship by recording 14 players in 7 matches with a video analysis system (Play-controller Prhomos Perugia, Italy). The average values of distances travelled in swimming was 1651 ± 450 m during the match, considering a playing time of 7 minutes per set (1680 s) but the actual duration of the match is 40 minutes (2400 s).

**RESULTS**

It was possible to derive the trend of passive drags from the towing tests at speeds of 1.2-1.4-1.6-1.8-2 m/sec.

A visual inspection of Figure 1 allows appreciating the larger values of passive drag in Wp compared to the Swim. The drag value relative to the acceleration phase was calculated in starts from standstill at velocities ≥ 1.9 m/sec. After the graphical analysis, the equations of passive drag obtained were converted into equations of power-drag (Table 1) according to the aforementioned steps (a and b):

<table>
<thead>
<tr>
<th>Velocity (m/sec)</th>
<th>Time played (sec)</th>
<th>Power drag (Swim) (W)</th>
<th>Power drag (Wp) (W)</th>
<th>Mechanical work (Swim) (J)</th>
<th>Mechanical work (Wp) (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>468</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.5</td>
<td>1097</td>
<td>8.36</td>
<td>14.82</td>
<td>9172</td>
<td>16254</td>
</tr>
<tr>
<td>1.35</td>
<td>360</td>
<td>122.16</td>
<td>251.27</td>
<td>43979</td>
<td>90458</td>
</tr>
<tr>
<td>1.9</td>
<td>475</td>
<td>204.92</td>
<td>788.76*</td>
<td>97338</td>
<td>374663*</td>
</tr>
<tr>
<td>total</td>
<td>2400</td>
<td></td>
<td></td>
<td>150489</td>
<td>481375</td>
</tr>
</tbody>
</table>

Considering normal freestyle swimming (Swim), the average mechanical power in a water polo match was 150489 J / 2400 s = 62.70 W, while in the WP model it was 481375 J / 2400 s = 200.57 W. Then, the second value was 3.2 times higher (Wm/Sm = 200.57/62.70 = 3.20).

**DISCUSSION**

During a water polo match, players perform a series of swimming sprints alternated to stationary phases, with mixed aerobic-anaerobic metabolic requirements. Several authors have investigated the functional model of water polo playing. Functional tests and metabolic investigations were carried out and the data obtained were related to the distance travelled at different speeds in a match (Pinnington et al. 1987, Hohmann & Frase 1992, Rudic et al. 1999, Platanou & Geladas 2006). Given the difficulty of quantifying the energy consumption of water polo players during the match, coaches plan training activities using normal swimming parameters as reference. However, water polo involves a different swimming technique that is much more expensive than normal freestyle, due to the need to keep the head out of the water, to control the ball and
other players. This position increases the resistance, which in water has a very significant impact due to the density of the medium. Furthermore, starting statically, the water polo player cannot push from the edge of the pool and thus uses the technical act of “trudgeon”. The acceleration phase requires additional energy expenditure, as it is overlaid by the higher drag due to the additional water mass in front of the swimmer. These considerations lead to revise the power values that are required in water polo players to move to a given swimming speed. Rodriguez (1994) found higher energy expenditure in tests performed by water polo compared to swimmers. Performing on a reference athlete a series of towing tests, we compared the values of drag, defining the power required to move, comparing the technique of water polo with normal freestyle. Estimating these values at different speeds during a model game, we suggest that the mechanical power required to the water polo players could be more than three-fold higher than that required for freestyle swimming at the same velocities.

This study highlights the importance of developing specific training programs for water polo, addressing the higher requirements of mechanical power, taking into account the specific movement techniques and comparing the distances travelled using different swimming techniques. However, further acquisitions will be performed with more athletes and matches, with the aim of identifying the specific differences between the models.

REFERENCES

Comparison of Combinations of Vectors to define the Plane of the Hand in order to calculate the Attack Angle during the Sculling Motion
Gomes, L.E.1, Melo, M.O.1, La Torre, M.1, Loss, J.F.1

1 Federal University of Rio Grande do Sul, Porto Alegre, Brazil

Studies into swimming propulsion describe different combinations of vectors to define the hand plane, which may alter the attack angle. The study aims (i) to verify the agreement between the attack angles calculated using different combinations of vectors, described in the literature and proposed by this study, to define the plane of the hand and (ii) to verify the variation in vector length of the methods found to be agreement in order to establish which method is most recommended when estimating the attack angle during sculling motion. The methods of calculating attack angles used from the literature and the one proposed by this study are in agreement. The variation in vector lengths of the proposed method was smaller than in the other vectors. We recommend using the proposed method to calculate the attack angle when analyzing this movement.

Key words: swimming, synchronized swimming, propulsion

INTRODUCTION
Propulsion is one of the key factors determining performance in human competitive swimming. However, as yet, this phenomenon is not fully understood and research to determine propulsive forces exerted by swimmers’ hands and arms has been strictly experimental. In this experimental research, studies into propulsion have been based on quasi-steady analyses, which depend on the assumption that the flow under steady conditions (constant velocity, constant attack and sweepback angles) is comparable to the flow during the actual swimming stroke. Quasi-steady analysis involves the following steps: (1) measuring the lift and drag forces acting on model hands in an open-water channel or in a wind tunnel for a wide range of hand orientations and, then calculating the lift and drag coefficients for each condition; (2) recording an underwater action of a swimmer using three-dimensional filming to determine the path, velocity and orientation of the hand relative to the water (attack and sweepback angles); (3) combining the results from steps 1 and 2 to determine the lift and drag forces using hydrodynamic equations.

Thus, in order to estimate hand forces in actual swimming, it is necessary to define the plane of the hand using landmarks to calculate attack angle during underwater action of a swimmer, since the attack angle is defined as the angle between the plane of the hand and the velocity vector of the hand (Payton and Bartlett, 1995). Unfortunately, problems may arise during this procedure, such as errors derived from the digitizing procedure, since the hand is hard to accurately digitize, because it is small and landmarks are placed close together (Payton and Bartlett, 1995).

From these arguments, Lauder et al. (2001) established the accuracy and reliability of current and newly proposed procedures for the reconstruction of hand velocity, sweepback and attack angles from underwater three-dimensional video analysis. They suggested that a greater distance between the landmarks would be beneficial in reducing errors arising from the digitizing procedure. Thus, five additional combinations of vectors were identified in order to define the plane of the hand. They have suggested that their proposed method, ‘Lauder 1’, improves accuracy when measuring the sweepback angle and, more importantly, the attack angle. However, there are a number of untested possible combinations that may be used to define the plane of the hand. Moreover, in order to achieve their purposes, Lauder et al. (2001) used a full-scale mechanical arm capable of simulating a controlled and highly repeatable underwater phase of the
front-crawl stroke. This mechanical arm has a restrict movement, since the medio-lateral direction was not considered as there was little or no hand motion in this direction due to the mechanical constraints.

Therefore, the purposes of this study, which involved synchronized swimmers and swimmers in a real situations, were (i) to verify the agreement between the attack angles calculated using different combinations of vectors, described in the literature and proposed by this study, to define the plane of the hand and (ii) to verify the variation in vector length of the methods found to be agreement in order to establish which method is most recommended when estimating the attack angle during sculling motion performed in a stationary vertical position (head above the water’s surface).

METHODS

The sample consisted of 16 participants (10 female synchronized swimmers and 6 female swimmers; age 13.7±2.3 years; height 1.56±0.11 m; weight 51.7±4.2 kg). In order to participate in the study, swimmers were required to have at least 6 months of exercise including sculling actions during their training program. All the participants or their guardians, in those cases where the participants were not legally capable, signed informed consent forms. The Ethics Committee of the university where the study was undertaken approved this study.

Recording took place in an indoor 25 m swimming pool. Two digital video cameras (JVC GR-DVL 9800) were positioned behind two glass windows in the side of the pool beneath the water level. The distance between these windows was 11.2 m. The sampling frequency of the video-camera was 50 fields-per-second. The Digital Video for Windows (Dvideow) software was used to track the markers. Each camera was connected to a computer, which was linked to an intranet in order to start the recording at same time for both cameras. The spatial resolution of the video system used was 1024 x 768 pixels.

A cube (0.80 m x 0.80 m x 0.80 m) was used as a control object with 12 control object points. The distance between the control object and a point equidistant between the windows was 6.7 m.

Landmarks were placed on the distal end of the third finger (1), metacarpophalangeal joints of the second (2) and fifth fingers (3), on the centre of the wrist joint (4) and the elbow (5) of the right limb, thus, the movement was considered symmetrical. After this, each participant performed a warm-up with sculling actions and familiarization with the experimental conditions with the right side of the body directed toward the equidistant point between the windows, in the position to be used during recording. All tasks were performed at the calibrated volume.

Each participant was asked to perform 20 seconds of sculling actions, maintaining a stationary vertical position with the head above the water surface and with the water at chin level in order to maintain all landmarks submerged during recording. This length of time was chosen in order to allow the participants sufficient time to stabilize the movement, while maintenance of the chosen position was the only criterion for standardization of sculling movement performance. Based on a qualitative criterion of stability, three cycles of sculling motion were chosen for digitalization.

Most of the studies found in the literature analyzed only one cycle of sculling motion. By contrast, in the present study, it was decided to analyze three consecutive cycles of sculling, chosen when the movement seemed to be stable. An experienced digitizer, using Dvideow software, manually digitized these. By analyzing three cycles, the influence of any random error that may occur during the digitalizing procedure was minimized.

Three-dimensional coordinates were obtained using a direct linear transformation method. The accuracy of the measurements was calculated and was equal to 0.004 m. The coefficient of variation was 0.5% when the distance between two rigidly linked markers at the known distance was reconstructed. All three-dimensional coordinates were smoothed using a seventh order low-pass Butterworth digital filter with cut-offs around 4 and 5 Hz, according to Residual Analysis (Winter, 2005).

The angle of attack was defined as the angle between the plane of the hand and the velocity vector of the hand (Payton and Bartlett, 1995). The plane of the hand was defined by the cross-product of vectors 1 and 2, which define a vector perpendicular (VP) to the plane of the hand. The velocity vector (v) was calculated using the raw coordinate data from the midpoint between the distal end of the second and fifth finger. The attack angle was calculated as 90° minus the angle between v and VP.

The calculations of the attack angle were made using the Matlab software (version 7.1). Figures 1 and 2 show the vectors that were used to reconstruct the hand orientation and Table 1 shows the different combinations of these vectors described by Schleihauf (1979), Berger et al. (1995), Lauder et al. (2001) (Lauder 1 – 5) and the new combination (NC) proposed by this study.

Table 1. Different combinations of vectors for the reconstruction of the plane of the hand (see Figures 1 and 2 for location).

<table>
<thead>
<tr>
<th>Combinations</th>
<th>Vector 1</th>
<th>Vector 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schleihauf</td>
<td>VE</td>
<td>VC</td>
</tr>
<tr>
<td>Berger et al.</td>
<td>VB</td>
<td>VE</td>
</tr>
<tr>
<td>Lauder 1</td>
<td>VD</td>
<td>VC</td>
</tr>
<tr>
<td>Lauder 2</td>
<td>VD</td>
<td>VI</td>
</tr>
<tr>
<td>Lauder 3</td>
<td>VH</td>
<td>VD</td>
</tr>
<tr>
<td>Lauder 4</td>
<td>VD</td>
<td>VG</td>
</tr>
<tr>
<td>Lauder 5</td>
<td>VF</td>
<td>VC</td>
</tr>
<tr>
<td>NC</td>
<td>VH</td>
<td>VI</td>
</tr>
</tbody>
</table>
RESULTS
According to figures 3 to 5, the combination of vectors for the reconstruction of the plane of the hand of Schleihauf is in agreement with the combination proposed in Lauder 1. The two methods are in agreement with the new combination (NC) proposed in this study. The variation in vector length of the methods found to be in agreement is presented in Table 2.

Table 2. Variation (%) in vector length of the methods that were in agreement.

<table>
<thead>
<tr>
<th>Combinations</th>
<th>Vector 1</th>
<th>Vector 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schleihauf</td>
<td>12</td>
<td>17.9</td>
</tr>
<tr>
<td>Lauder 1</td>
<td>7.2</td>
<td>17.9</td>
</tr>
<tr>
<td>NC</td>
<td>7.8</td>
<td>8.4</td>
</tr>
</tbody>
</table>

DISCUSSION
The results of this study show that the attack angles calculated from Schleihaup, Lauder 1 and NC methods are in agreement, that is, the three methods may be used interchangeably in order to calculate the attack angle. However, when the variation in vector length of these methods is observed there are greater variations between the Schleihaup and Lauder 1 methods.

Lauder at al. (2001) also found the Schleihaup and Lauder 1 methods to be very similar and the mean percentage error in vector length reconstruction was smaller in Lauder 1 than Schleihaup. Furthermore, they concluded that the method proposed by Berger at al. (1995) differed from both Schleihaup and Lauder 1. This finding is in accordance with the findings of this study, since the method from Berger et al. (1995) was found not to be in agreement with the Schleihaup and Lauder 1 methods.

The plane of the hand is found by calculating the cross product between two vectors, which represent the plane of the hand. These two vectors are calculated from three points, as in the Berger et al. (1995) and NC methods. Nevertheless, Schleihaup and Lauder 1 use four points to define the plane of the hand, although the points do not necessarily lie in a single plane.

Although Lauder at al. (2001) suggested that, since the method from Berger et al. (1995) requires fewer points for reconstruction, it could offer a clear advantage in real life, when some of the points may be obscured by water turbulence. Our results suggest it is better to use Schleihaup, Lauder 1 or NC when analyzing the sculling motion. Moreover, the vectors used in the method from Berger et al. (1995) appear to be more sensitive to slight changes in the hand shape than those used in Schleihaup, Lauder 1 and NC.

Using three points may present an advantage, and the NC method is better than the Schleihaup and Lauder 1 methods. Furthermore, Lauder 1 and NC presented a smaller variation in their vector lengths than the methods from Schleihaup (1979) and Berger et al. (1995) because there is a greater distance between the points, which might be beneficial in reducing error. In addition, the vectors used in the NC method presented a smaller variation in their lengths than other two. Thus, it is suggested that the NC method should be used in order to calculate the attack angle during analysis of sculling motion.

CONCLUSION
The attack angles calculated from Schleihaup, Lauder 1 and NC (the new method proposed by this study) methods were found to be in agreement. However, there was less variation in the length of the vectors used in the NC method than in those of the other two methods. Therefore, given that the results of the present study were obtained in a real situation as opposed to a model, we suggest using the NC method to calculate the attack angle in the analysis of the sculling motion.

REFERENCES
The Acute Effect of Front Crawl Sprint-resisted Swimming on the Direction of the Resultant Force of the Hand

Gourgoulis, V.1, Aggeloussis, N.1, Mavridis, G.1, Boli, A.1, Toubekis, A.G.2, Kasimatis, P.1, Vezos, N.1, Mavrommatis, G.1

1Democritus University of Thrace, Komotini, Greece
2Kapodistrian University of Athens, Athens, Greece

The aim of the study was to investigate the acute effect of front crawl sprint-resisted swimming on the direction of the resultant force of the hand. Five female swimmers swam 25 m with maximal intensity with and without added resistance. The underwater motion of the hand was recorded using 4 cameras (60 Hz) and the Ariel Performance Analysis System was used for the digitization. The results showed that the magnitude of the drag and lift forces, as well as the magnitude of the resultant force was not modified significantly during resisted swimming. However, the angle formed between the resultant force and the axis of the swimming propulsion was decreased significantly in the pull phase. Thus, it could be speculated that sprint-resisted swimming could contribute to the learning of a more effective application of the propulsive forces.

Key words: front crawl, resisted swimming, resultant force.

INTRODUCTION

In front crawl swimming, the propulsive forces generated mainly from the hands. The way swimmers use their arms to apply these forces is decisive for effective swimming propulsion (Arellano, 1999). The resultant propulsive force produced by a swimmer's hand is a combination of two types of propulsive forces: the drag force and the lift force. For effective swimming propulsion the resultant of these two forces should be aimed, as much as possible, in the swimming direction (Rushall et al., 1994; Schleierhau, 2004; Toussaint et al., 2000). In addition, in front crawl swimming, which is a stroke with alternate arm movement, it is necessary to avoid significant deviations of the resultant force vector from the swimming direction, since this may cause undesirable sideways and vertical deviations of the body, increasing the resistive forces (Vorontsov & Rumyanstev, 2000).

Moreover, it is considered that training methods such as sprint-resisted swimming where the swimmers swim against a resistance in addition to the natural water resistance are more effective for the improvement of the swimming performance than dry land training methods (Girol et al., 2007; Llop et al., 2006; Williams et al., 2001). In the past, the acute effect of sprint-resisted swimming has been investigated in various kinematic characteristics of the stroke, such as the time of the underwater motion of the hand, the velocity of the hand, its medial – lateral displacements, the stroke rate, the stroke depth and the swimming velocity (Maglischo et al., 1984; Maglischo et al., 1985; Williams et al., 2001).

However, there is a lack of data regarding the effect of the sprint-resisted swimming on the direction of the resultant force. It could be speculated that, if during sprint resisted swimming the angle between the resultant force vector and the axis of swimming propulsion is decreased, then this training method could probably contribute to the learning of a more effective application of the propulsive forces. Therefore, the aim of the present study was to examine the acute effect of front crawl sprint-resisted swimming on the direction of the resultant force of the hand.

METHODS

Five female competitive swimmers participated in the study (age: 20.4 ± 6.1 years, height: 1.73 ± 0.03 m, body mass: 59.1 ± 6.67 kg, best performance in the 100 m front crawl swimming: 62.59 ± 2.88 s). Each swimmer swam in randomized order two trials of 25 m front crawl with maximal intensity. One of the trials was performed without added resistance and the other one was performed with an added resistance. A bowl with a diameter of 32 cm and a capacity of 6 l was used as added resistance. The bowl was pulled by its convex side and it was tethered on a belt, which was around the waist of each swimmer, with a 1.5 m long elastic tube (Mavridis et al., 2006). All trials were executed using a six-beat kick and without breathing in the middle of the distance, where the underwater stroke was recorded.

The underwater motion of the right hand was recorded using four cameras (60 Hz), which were positioned behind four stationary periscope systems. The synchronisation of the cameras was achieved using a LED system visible in the field of view of each camera. A calibration frame with dimensions of 1m x 3m x 1m for the transverse (X), the longitudinal (Y) and the vertical (Z) directions, respectively, containing 24 control points, was used for the calibration of the recorded space in the middle of the 25 m swimming pool (Gourgoulis et al., 2008a). Before filming, selected points were marked on each swimmer's skin corresponding to the acromion of the right shoulder, the greater trochanter of the right and left hip, and four points on the right hand: the center of the wrist, the tip of the middle finger, the index and the little finger metacarpophalangeal joints. These points were digitized using the Ariel Performance Analysis System (Ariel Dynamics Inc., San Diego CA, USA) and their three dimensional coordinates were calculated using the direct linear transformation procedure.

For a detailed description and quantification, the underwater stroke of the right hand was divided into three distinct phases: (a) entry and catch, (b) pull and (c) push (Chollet et al., 2000). The hydrodynamic coefficients and the methodology presented by Sanders (1999) were used for the estimation of the drag force, the lift force and the resultant force of the swimmer’s hand. Moreover, the component of the resultant force in the swimming direction, defined as the effective propulsive force generated from the swimmer’s hand, and the angle between the resultant force and the axis of propulsion were calculated (Gourgoulis et al., 2008c). The stroke length, the stroke rate and the mean swimming velocity were also calculated (Gourgoulis et al., 2008b).

For the statistical treatment of the data, the t-test for dependent samples was used. The normal distribution and the homogeneity of variance were verified using the Kolmogorov – Smirnov test and the Levene test, respectively. The significance level was set as p < 0.05.

RESULTS

During resisted swimming the stroke length, the stroke rate and the mean swimming velocity were decreased significantly (Table 1).

Table 1. Stroke length (m), stroke rate (cycles s⁻¹) and mean swimming velocity (m s⁻¹) during front crawl swimming with and without added resistance.

<table>
<thead>
<tr>
<th></th>
<th>Without added resistance</th>
<th>With added resistance</th>
<th>t- value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke length</td>
<td>1.88 ± 0.07</td>
<td>1.28 ± 0.08</td>
<td>13.155*</td>
</tr>
<tr>
<td>Stroke rate</td>
<td>0.84 ± 0.04</td>
<td>0.74 ± 0.06</td>
<td>5.188*</td>
</tr>
<tr>
<td>Mean swimming velocity</td>
<td>1.57 ± 0.09</td>
<td>0.95 ± 0.13</td>
<td>26.750*</td>
</tr>
</tbody>
</table>

*p < 0.05

During the pull and the push phase, the magnitude of the mean drag force, the mean lift force, the mean resultant force and the mean effective propulsive force, were not altered significantly, in comparison with free swimming. On the other hand, the angle between the vector of the resultant force and the axis of swimming propulsion was decreased significantly during the pull phase in the resisted swimming condition. This modification was not observed during the push phase (Table 2).
Table 2. Mean drag force (N), mean lift force (N), mean resultant force (N), mean effective force (N), and angle between the vector of the resultant force and the axis of swimming propulsion (deg) during front crawl swimming with and without added resistance.

<table>
<thead>
<tr>
<th></th>
<th>Without added resistance</th>
<th>With added resistance</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pull phase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drag force</td>
<td>9.20 ± 2.57</td>
<td>9.16 ± 2.46</td>
<td>0.028</td>
</tr>
<tr>
<td>Lift force</td>
<td>7.50 ± 2.45</td>
<td>5.76 ± 1.59</td>
<td>2.679</td>
</tr>
<tr>
<td>Resultant force</td>
<td>12.34 ± 2.59</td>
<td>11.21 ± 2.38</td>
<td>1.061</td>
</tr>
<tr>
<td>Effective force</td>
<td>9.47 ± 1.71</td>
<td>10.04 ± 2.12</td>
<td>0.532</td>
</tr>
<tr>
<td>Angle between the vector of the resultant force and the axis of swimming propulsion</td>
<td>36.31 ± 14.73</td>
<td>13.26 ± 15.37</td>
<td>2.877*</td>
</tr>
<tr>
<td>Push phase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drag force</td>
<td>7.27 ± 2.40</td>
<td>8.76 ± 4.62</td>
<td>0.562</td>
</tr>
<tr>
<td>Lift force</td>
<td>12.59 ± 2.32</td>
<td>11.70 ± 4.52</td>
<td>0.630</td>
</tr>
<tr>
<td>Resultant force</td>
<td>14.93 ± 2.50</td>
<td>14.85 ± 6.28</td>
<td>0.033</td>
</tr>
<tr>
<td>Effective force</td>
<td>12.89 ± 2.06</td>
<td>13.19 ± 6.44</td>
<td>0.121</td>
</tr>
<tr>
<td>Angle between the vector of the resultant force and the axis of swimming propulsion</td>
<td>-5.18 ± 16.76</td>
<td>-16.09 ± 9.56</td>
<td>1.462</td>
</tr>
</tbody>
</table>

*p < 0.05

DISCUSSION
The results showed that during resisted swimming the mean swimming velocity decreased significantly. This was expected, because both the stroke length, as well as the stroke rate decreased due to the increased resistance that should be overcame by the swimmers (Llop et al., 2006; Maglischo et al., 1985; Williams et al., 2001).

During sprint-resisted swimming no significant modifications were observed in the magnitude of the drag and lift forces, in any of the propulsive phases of the underwater stroke. Consequently, it was not observed any significant modification in the magnitude of the resultant force and the effective force. However, the drag force seems to predominate more against lift force in the pull phase during resisted swimming, in comparison with free swimming. Although this fact was not statistically significant, it could be seen as a positive modification, as according to Rushall et al. (1994), Sanders (1998) and Maglischo (2003), it is more effective when swimmers rely more on drag, rather than on lift forces. Such combination of the drag and lift forces has as consequence to maximize their contribution to the forward direction and as much as possible of the resultant force to be aimed in the swimming direction. Optimaly, the angle between the resultant force and the axis of swimming propulsion should be as close as possible to zero (Schleicher, 2004; Vorontsov & Rumyantsev, 2000). In the present study, although the magnitude of the drag and the lift forces were not altered significantly, the angle formed between the resultant force and the axis of swimming propulsion was decreased significantly in the pull phase during resisted swimming, in comparison with free swimming. The mean value of the above mentioned angle was decreased from approximately 36 degrees during free swimming to 13 degrees during resisted swimming and thus the resultant force was steered more in the forward swimming direction.

CONCLUSION
The main findings of the present study indicate that although the magnitude of the drag and lift forces, as well as the magnitude of the resultant force and the effective propulsive force were not modified significantly during resisted swimming, in comparison with free swimming, the angle formed between the resultant force and the axis of swimming propulsion was decreased significantly in the pull phase. Thus, it could be speculated that front crawl sprint-resisted swimming with the concrete added resistance could be considered a specific trainings form, which probably could contribute to the learning of a more effective application of the propulsive forces during the pull phase.

REFERENCES


Relationship between Eggbeater Kick and Support Scull Skills, and Isokinetic Peak Torque

Homma, M.¹

¹University of Tsukuba, Tsukuba, Japan

Eggbeater kick and support scull are essential basic propulsive techniques in synchronized swimming. The aim of the present study was to ascertain the relationship between muscle strength, and eggbeater kick skills and vertical position support skills in elite synchronized swimmers. The isokinetic peak torque of legs, trunk and shoulders were measured using the BIODEX System 3. From the findings in this study, to improve eggbeater kick skills, the importance of strengthening the muscles associated with hip flexion such as the hamstrings, rectus abdominis, and psoas major was suggested. To improve the support scull skills, upper arm abductors such as the infraspinatus and teres minor should be trained and the muscles around the scapula should be strengthened in proper balance.

Key words: propulsive techniques, muscle strength, synchronized swimming

INTRODUCTION

The eggbeater kick (Figure 1) is a rotational movement of the lower legs in which a swimmer opens the legs sideways with the hip joint flexed and bends the knees while swivelling both feet in opposing circles. The load above the water surface is at least 13 kg when both arms are raised using this kick (Homma, 2000). Thus, strength to control the body, hip and leg muscles is needed to elevate the body during synchronized swimming routines. Support scull is a rotational movement of the forearms in which a swimmer bends the elbows and sculls the water using the forearms via internal and external shoulder rotations (Homma and Homma, 2006). About 14 - 15 kg of load is applied at the maximum height above the water surface to support a vertical posture (Figure 2), which is the basic position in synchronized swimming (Homma, 2000). Thus, the body can only be kept elevated by sculling. Support scull is an unusual movement in which the forearms are supinated while the shoulders are externally rotated, and the muscles involved with internal and external shoulder rotation are thought to be involved. Stress fractures of the ulna mostly, due to sculling, have been reported in junior synchronized swimmers (Nagano and Ohata, 1982).

A previous study of the relationship between eggbeater kick skills and leg muscle strength and between the cross-sectional area of the thigh and abdominal muscles for elite synchronized swimmers found a correlation with the isokinetic peak torque, but not the cross-sectional area of the legs (Homma and Kuno, 2001). The isokinetic peak torque for knee flexion/extension, internal/external shoulder rotation and hip abduction/adduction was measured in the study, and a significant correlation was seen between moderate-speed hip abduction and knee flexion. This finding suggested that the eggbeater kick can be reinforced by strengthening the hamstrings, sartorius, gluteus medius and gluteus minimus by training at moderate speed.

The aim of the present study was to ascertain the relationship between eggbeater kick skills (technical ability of eggbeater kick) and the leg and trunk muscle strength, and the relationship between vertical position support skills (technical ability for supporting vertical position) and muscle strength of internal and external shoulder rotation.

METHODS

Ten female synchronized swimmers (average height, body mass and age, 1.64 ± 0.04 m, 54.5 ± 2.8 kg, 23.8 ± 1.9 yrs, respectively), silver-medallists at the 2007 World Championships, who were all candidates for the 2008 Beijing Olympic Games, participated in the study.

Eggbeater kick skills and vertical position support skills were assessed based on their respective test scores obtained during the first qualifying trial for the 2008 Beijing Olympics in September 2007 (Qualifying Trial) and the skill evaluation test for Beijing Olympic candidates in June 2007 (Skill Evaluation Test).

Eggbeater kick skills were assessed based on the two scores: 1) eggbeater kick (EB) score and 2) height score. International judges and national coaches determined scores of up to 5 points in half-point increments. EB score obtained as one of the routine set of tests conducted during the Qualifying Trial. The routine set comprised five features that are essential for performing a routine and included propulsive techniques and figures. During the assessment of eggbeater kick skills, swimmers were required to raise both arms and move forward while counting to 12. Swimmers were assessed based on height, stability and smoothness. Height score obtained as part of the Skill Evaluation Test. Swimmers moved forward 5 m while sculling in the water without rais-
ing the arms. Swimmers were subjectively assessed based on height.

Vertical position support skills were assessed based on the two scores: 1) vertical position score and 2) design score. The vertical position support skills were assessed by instructing each swimmer to support the highest possible vertical position for 15 seconds and enter the water while supporting this position. This test most closely reflects support scull skills. Vertical position score obtained as part of a routine set of tests conducted during the Qualifying Trial. International judges determined vertical position scores which swimmers were assessed based on height, presence, stability, and correct position. Design scores (vertical position correctness and extension) were determined by the national coach and six international judges with a maximum score of 5 points in half-point increments during the Skill Evaluation Test.

The isokinetic peak torque for knee flexion and extension (angle rate: 60 or 180˚/s), trunk flexion and extension (angle rate: 60 or 120˚/s) and shoulder internal and external rotations (angle rate: 60 or 120˚/s) were measured using the BIODEX System 3 (Biodex Medical Systems Inc.). Isokinetic peak torque per body weight was also calculated.

The relationship between EB and height score to the isokinetic peak torque for knee extension and flexion or trunk extension and flexion and the relationship between vertical position and design scores to the isokinetic peak torque for shoulder internal and external rotations were analyzed using Spearman’s rank correlation coefficients with the level of significance set at p<0.05.

RESULTS

Table 1 shows isokinetic peak torque of knee and trunk. There were no significant differences between right and left knees in isokinetic peak torque. Height and EB scores significantly correlated (r=0.814, p<0.01). As shown in Table 2, both EB and height scores significantly correlated with 60˚/s and 180˚/s (left) knee flexion. Height score significantly correlated with 60˚/s trunk flexion. With respect to isokinetic peak torque per body weight, correlations between EB score and 60 or 180˚/s (left) knee flexion per body weight, and between height score and 60˚/s trunk flexion per body weight were significant.

Table 3 shows vertical position support skill scores and isokinetic peak torque of internal and external shoulder rotations. There were no significant differences between right and left shoulders in isokinetic peak torque. In terms of vertical position support skills, vertical position score significantly correlated with design scores (r=0.773, p<0.01). As shown in Table 4, vertical position score significantly correlated with 60˚/s and 120˚/s right external shoulder rotations per body weight. Design scores significantly correlated with 60˚/s and 120˚/s external shoulder rotations per body weight.

Table 1. Isokinetic peak torque of knee and trunk of elite female Japanese synchronized swimmers determined using Biodex System 3.

<table>
<thead>
<tr>
<th>Knee (Nm)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension, right 60˚/s</td>
<td>120.9</td>
<td>16.5</td>
</tr>
<tr>
<td>Extension, left 60˚/s</td>
<td>119.6</td>
<td>18.5</td>
</tr>
<tr>
<td>Flexion, right 60˚/s</td>
<td>72.2</td>
<td>12.6</td>
</tr>
<tr>
<td>Flexion, left 60˚/s</td>
<td>64.3</td>
<td>8.5</td>
</tr>
<tr>
<td>Extension, right 180˚/s</td>
<td>86.2</td>
<td>12.7</td>
</tr>
<tr>
<td>Extension, left 180˚/s</td>
<td>85.9</td>
<td>13.3</td>
</tr>
<tr>
<td>Flexion, right 180˚/s</td>
<td>57.0</td>
<td>7.5</td>
</tr>
<tr>
<td>Flexion, left 180˚/s</td>
<td>52.3</td>
<td>6.8</td>
</tr>
<tr>
<td>Trunk (Nm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension, 60˚/s</td>
<td>224.7</td>
<td>55.2</td>
</tr>
<tr>
<td>Flexion, 60˚/s</td>
<td>140.9</td>
<td>33.5</td>
</tr>
<tr>
<td>Extension, 120˚/s</td>
<td>208.2</td>
<td>37.0</td>
</tr>
<tr>
<td>Flexion, 120˚/s</td>
<td>116.0</td>
<td>18.1</td>
</tr>
</tbody>
</table>

Table 2. Correlations (r) between eggbeater kick skill scores and isokinetic peak torque of knee and trunk for elite female Japanese synchronized swimmers. (*p<0.05, **p<0.01)

<table>
<thead>
<tr>
<th>Knee extension and flexion (Nm)</th>
<th>vs EB score(r)</th>
<th>vs Height score(r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension, 60˚/s</td>
<td>0.354</td>
<td>0.272</td>
</tr>
<tr>
<td>Flexion, 60˚/s</td>
<td>0.177</td>
<td>0.735 *</td>
</tr>
<tr>
<td>Extension, 180˚/s</td>
<td>0.508</td>
<td>0.475</td>
</tr>
<tr>
<td>Flexion, 180˚/s</td>
<td>0.245</td>
<td>0.711 *</td>
</tr>
</tbody>
</table>

Table 3. Isokinetic peak torque of internal and external shoulder rotations determined in elite female Japanese synchronized swimmers using Biodex System 3.

<table>
<thead>
<tr>
<th>Shoulder rotation (Nm)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal rotation, right 60˚/s</td>
<td>25.3</td>
<td>3.7</td>
</tr>
<tr>
<td>Internal rotation, left 60˚/s</td>
<td>25.6</td>
<td>3.9</td>
</tr>
<tr>
<td>External rotation, right 60˚/s</td>
<td>18.1</td>
<td>2.7</td>
</tr>
<tr>
<td>External rotation, left 60˚/s</td>
<td>17.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Internal rotation, right 120˚/s</td>
<td>22.7</td>
<td>3.8</td>
</tr>
<tr>
<td>Internal rotation, left 120˚/s</td>
<td>23.4</td>
<td>3.6</td>
</tr>
<tr>
<td>External rotation, right 120˚/s</td>
<td>15.8</td>
<td>2.7</td>
</tr>
<tr>
<td>External rotation, left 120˚/s</td>
<td>14.8</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 4. Correlations (r) between scores of supporting vertical position and isokinetic peak torque (Nm/BW) of internal and external shoulder rotation in elite Japanese female synchronized swimmers. (* p < 0.05).

<table>
<thead>
<tr>
<th>Shoulder rotation per body weight (Nm/BW)</th>
<th>vs Vertical position score(r)</th>
<th>vs Design score(r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal rotation, 60˚/s</td>
<td>0.396</td>
<td>0.140</td>
</tr>
<tr>
<td>External rotation, 60˚/s</td>
<td>0.633</td>
<td>0.478</td>
</tr>
<tr>
<td>Internal rotation, 120˚/s</td>
<td>0.366</td>
<td>0.262</td>
</tr>
<tr>
<td>External rotation, 120˚/s</td>
<td>0.646</td>
<td>0.463</td>
</tr>
</tbody>
</table>
DISCUSSION
The results of the present study confirmed a relationship between eggbeater kick skills and the isokinetic peak torque for 60 or 180°/s (left) knee flexion or 60°/s trunk flexion. Homma and Homma (2005) suggested that when teaching the eggbeater kick, it is important to elevate the knees above the greater trochanter and elevate the heels near the gluteal region. Executing the kick is thought to involve low- and moderate-speed and low-speed hip and knee flexion, respectively, suggesting the importance of strengthening the muscles associated with hip flexion such as the hamstrings, rectus abdominis, and psoas major. This finding supported the previous study for elite synchronized swimmers (Homma and Kuno, 2001) that strengthening the hamstrings, sartorius, gluteus medius and gluteus minimus by training at moderate speed can reinforce the eggbeater kick. On the other hand, hip abduction was not measured in the present study due to technical limitation of analyzer. Therefore, hip abduction could not be compared with previous findings (Homma and Kuno, 2001), but knee flexion was comparable, suggesting a close correlation between eggbeater kick skills and left knee flexion. Furthermore, the present study identified a correlation with low-speed trunk flexion, suggesting the importance of strengthening the rectus abdominis, obliquus internus abdominis, psoas major and rectus femoris that bend the trunk, by training at low speed.

The significant relationship between external shoulder rotation and vertical position support skills might have been due to the specificity of support scull movements. The support scull is a rotational movement of the forearms with bent elbows, and it is an unusual movement where a swimmer bends the elbows and externally rotates the shoulder while supinating the forearms with the palms facing the face (Homma and Homma, 2006). Internal shoulder rotation is occasionally used during routine activities, whereas external shoulder rotation is rare. Therefore, rather than individual differences in internal rotation, those in external rotation are closely related to support scull skills. Therefore, upper arm abductors such as the infraspinatus and teres minor should be trained. These muscles are called inner muscles, and since they are in the deep layers of the shoulder, athletes are not often aware of them. Unlike outer muscles, training inner muscles is more difficult and should be performed using rubber bands and light-weight dumbbells, with careful monitoring of muscle movement. Also, large muscles that connect the trunk and upper arms such as the pectoralis major and latissimus dorsi are important when sculling with fixed shoulders. Therefore, to improve support scull skills, the muscles around the scapula should be strengthened in proper balance. Although we reached these implications in the present study, how the muscles contribute to the eggbeater kick or sculling movements should be analyzed with EMG in future studies. Since eggbeater kick and sculling movements are symmetry, there were no significant differences between right and left peak torques. However, for only one side, some significant correlations between peak torques and scores were obtained, therefore, dominance assessment is needed in a future.

The BIODEX was used in the present study to measure the isokinetic peak torque of single joint movements. As they differ from the natural output characteristics for synchronized swimming, a method of quantifying the muscle strength and power required for floating using the support scull and eggbeater kick is required. However, periodic checking of the muscle strength of synchronized swimmers using a muscle function analyzer is useful for training purposes, and continued use of the system as a control test is warranted.

REFERENCES

ACKNOWLEDGEMENTS
I would like to thank the project research, Institute of Sport and Health Sciences in University of Tsukuba for a grant that made it possible to complete this study.
A Biomechanical Comparison of Elite Swimmers Start Performance Using the Traditional Track Start and the New Kick Start

Honda, K.E.1,2, Sinclair, P.J.1, Mason, B.R.1 & Pease, D.L.2
1The University of Sydney, Australia
2Australian Institute of Sport, Australia

The international governing body for swimming ‘FINA’ has approved the development of a new starting block (Omega, OSB11) with an inclined kick plate at the rear of the block. The purpose of this study was to determine the effects of the new start platform on performance relative to that of the traditional track start. Fourteen elite swimmers completed three ‘dive and glide’ starts using the kick plate and three traditional track starts. Results indicated the kick start to be a significantly faster start than the track start. The kick start was significantly faster off the block with a higher horizontal velocity at take off and an increased on block horizontal force. This advantage was maintained through the time to 5 m and 7.5 m. It is recommended that time adapting to the new block and this new starting technique.

Keywords: biomechanics, swimming start, track start, kick start, OSB11.

INTRODUCTION

The goal of a swimming race is to complete the required distance in the least amount of time, with races being won or lost by a hundredth of a second. A race is made up of a number of key components, the free swim (where the athlete is stroking), starts, turns and finishes. The velocity achieved by a swimmer is greatest during the starting phase, therefore it is important for a swimmer to maintain the velocity achieved off the start block for as long as possible before slowing to race pace (Welcher, Hinrichs, & George, 2008). Although the time a swimmer spends starting is less than in the free swim and turning phases, an effective start is important for success (Miller, Hay, & Wilson, 1984).

Researchers have broken down the swimming start into three phases (Guimaraes & Hay 1985; Schnabel & Kuchler 1998). Block time (start signal until toes off block) flight time (time spent in the air), and underwater or glide time (from water entry until first kick). Swimmers can only attain maximum performances during the start phase if they are able to skillfully execute all three phases (Schnabel & Kuchler 1998).

The performance measure of a start is usually set to time to 15 m (Cossor & Mason 2001, incorporated in this is the block time, flight time and the water time (Guimaraes & Hay 1985). Ruschel et al., (2007) suggest that water phase is intimately connected to the individual characteristics of each subject, like the streamline position and the underwater stroke technique used, being influenced by several factors and actions that happen from the instant of entry in the water to the beginning of the first kicking and the first stroke movements. A study by Guimaraes and Hay (1985) observed 94% of the variance in start time was attributed to the water time.

The requirements for a superior start include a fast reaction time, significant jumping power, a high take-off velocity and a decrease in drag force during entry. A low resistance streamline position during underwater gliding to minimize the loss of horizontal velocity as well as an increase in propulsive efficiency during the transition stage can assist in a superior start (Schnabel & Kuchler 1998; Breed & Young 2003).

Over the last 40 years, the swim start technique has continued to evolve, from the conventional or arm swing start to the grab start and the track start. In the late 1970’s the track start debuted and has gained in popularity and proven successful in international competition. The track start has one foot at the front edge of the block, the other placed towards the back on the starting platform with hands grabbing the front edge of the block. Due to these changes in the swimmers foot placement, the track start employs a wider base of support than the grab start resulting in greater stability for the swimmer (Shin & Groppel, 1986; Breed & McElroy, 2000).

In 2009 a new starting technique has developed with the introduction of an incline or ‘kick’ plate mounted to the start platform. This newly designed start block by Omega (OSB11, Corgémont, Switzerland, Figure 1), has the international governing body for swimming ‘FINA’ approval and has allowed the development of the kick start. The kick start is essentially a modified track start that allows the rear foot to be raised off the platform and placed upon a kick plate. The kick plate is angled at 30 deg to the surface of the block and can be moved through five different locations on the starting platform. Omega claims that “tests undertaken by top level swimmers showed faster races versus a standard block” however no data was provided to support this statement. To date, no study has examined the biomechanical factors associated with a successful start using the OSB11. Hence the purpose of this study was to determine the effects of the new angled start platform on performance relative to that of the traditional track start. This study hypothesized that the kick start would increase the amount of horizontal force being applied, enabling faster start times and greater horizontal velocity when compared to the track start.

METHODS

The subject cohort for this study consisted of fourteen elite swimming subjects (9 male aged 20.8 ± 3.0 years, 5 female aged 21.4 ± 2.8 years) all of which were members of the Australian Institute of Sport (AIS) Swim Team. All participants had personal best times which attained a minimum of 850 FINA points (http://www.fina.org/swimming/FINA points/index.php). The experimental procedure was approved by the AIS ethics committee.

The participants completed a warm up, based around their pre-race routine which consisted of some sprint and dive drills to ensure the athlete was ready to perform at their maximal capacity. Before the commencement of the testing session their weight was obtained using the force platform built into the start block. This was used to normalise the force data.

Normal competitive starting procedures were used for each trial. The participants were instructed to perform a maximal effort dive and glide until their forward momentum ceased, while not kicking or swimming. The participants completed three ‘dive and glide’ starts using the kick plate in their preferred position and three traditional track starts, in a randomised sequence.

‘Wetplate’ is the proprietary system used to analyse the starts. It is
comprised of an instrumented start block constructed using a Kistler force platform (Z20314, Winterthur, Switzerland, figure 2). Wetplate not only allows for the determination of the overall force profile of the start itself but also allows measurement of the grab force through two Kistler tri-axial transducers (9601A) placed in a bar at the front of the start block. The contribution of the rear foot is also measured on a second instrumented incline plate by 4 Kistler tri-axial transducers (9251A) developed to the specifications of the OSB11 start platform. The system includes a series of calibrated high speed digital cameras (Pulnix, TMC-6740GE), one above water to capture the start and entry with 3 underwater to obtain vision from 0m to 15m. The timing to 5m and 7.5m was assessed using ‘SwimTrak’ an analogue video camera timing system in which the cameras (Samsung, SCC-C4301P) were located perpendicular to the plane of motion at 0m, 5m and 7.5m. Deinterlacing the video signal allowed for the respective split times to be determined to a resolution of 1/50th of a second. All calculations were timed from when the participants head passed the specified points.

Figure 2: The AIS Wetplate Instrumented Starting Platform with Grab bar and Kick Plate

Data was collected for a total of 12 seconds, 1 second prior to and 11 seconds after the start signal. The start signal is integrated into the analysis system and triggers the data collection from the force plates and the cameras. A 10Hz Butterworth low pass digital filter was applied to the force data collected through Wetplate.

A two way repeated measures analysis of variance (ANOVA) was performed to assess the main effects of style (Kick Start vs. Track Start) and gender (male vs. female). When the assumption of equal variances was violated, significance was adjusted using the Greenhouse-Geisser procedure (Vincent, 1995). All presented values are expressed as mean ± SD, and P values less than or equal to 0.05 were considered as statistically significant.

RESULTS

The performance differences between the kick start and traditional track start are presented in Table 1. Males recorded faster times and higher velocities than females for both the track start and the kick start. However there were no significant interactions between gender and the style of the start for any of the variables and so results were pooled in Table 1. All force data presented has been normalised to the participant’s weight and expressed in Body Weights (BW).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Kick Start</th>
<th>Track Start</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to 5m (s)</td>
<td>1.62 ± 0.01</td>
<td>1.66 ± 0.01</td>
<td>0.002**</td>
</tr>
<tr>
<td>Time to 7.5m (s)</td>
<td>2.69 ± 0.02</td>
<td>2.73 ± 0.02</td>
<td>0.032*</td>
</tr>
<tr>
<td>Time on Block (s)</td>
<td>0.77 ± 0.01</td>
<td>0.80 ± 0.01</td>
<td>0.003**</td>
</tr>
<tr>
<td>Take-off Horizontal Force (m/s²)</td>
<td>4.48 ± 0.04</td>
<td>4.41 ± 0.03</td>
<td>0.009**</td>
</tr>
<tr>
<td>Average Velocity between 5m &amp; 7.5m (m/s⁻¹)</td>
<td>2.39 ± 0.04</td>
<td>2.37 ± 0.04</td>
<td>0.644</td>
</tr>
<tr>
<td>Average Horizontal Force (BW)</td>
<td>0.60 ± 0.01</td>
<td>0.57 ± 0.01</td>
<td>0.003**</td>
</tr>
<tr>
<td>Peak Horizontal Force on the Block (BW)</td>
<td>1.13 ± 0.04</td>
<td>1.09 ± 0.04</td>
<td>0.151</td>
</tr>
</tbody>
</table>

* Significant difference between Kick Start and Track Start p < 0.05
** Significant difference between Kick Start and Track Start p < 0.01

DISCUSSION

This study hypothesized that the kick start would increase the amount of horizontal force being applied when compared to the track start, enabling shorter start times and greater horizontal velocity off the block. Results showed the kick start was the significantly superior method when looking at performance indicators of time to 5m and time to 7.5m.

This study included nine male subjects, but only five females. It is possible the different subject numbers may have masked differences between genders owing to a reduced statistical power. The main intent of this study, however, was to investigate differences between the start techniques, not to determine whether strategies would be different for males and females.

The new block allows the kick start to achieve an average on block time of 0.77s compared to the track starts of 0.80s. This was significant (p<0.01) as the kick start had shorter off block times by 0.03 second. Breed and McElroy (2000) have previously found a 0.03 second difference in on block time between the Grab and the Track start to be insignificant, as the variance between their start was high (0.06s, 0.07s standard deviations for the grab and track start respectively). Their study utilised novice swimmers, whereas the present study was conducted with elite swimmers in which variance was significantly smaller than that of 0.01s for both the kick and track starts. Shin and Groppel (1986) found the take-off time of the track start was significantly faster (p<0.05) than that of the grab start. This further highlights the benefit the kick start has, not only over the track start, but also other starts.

The advantage which was provided by the kick start over the track start was able to carry through to 5m and 7.5m, where it held a significant 0.04 second gain at both distances. This consistent difference indicated the improvement was established on the block and not greatly enhanced thereafter. No prior study has found the track start to be significantly faster than the grab start to a set distance ranging from 5m to 11m (Breed and McElroy, 2000); however most researchers have suggested that the track start is a viable and equally effective alternate to the grab start, depending on the individual. The track start has been reported as equivalent to the grab start due to trade-offs in take-off velocity and block time (Allen et al., 1999), yet others have found the track start superior to the grab start when solely comparing performance times (Counsilman et al., 1988). The fact that all participants found the kick start to be their faster start to 5m and 7.5m showed its superiority compared to the track start.

Counsilman et al. (1988) stated that, for the track start, maximal momentum is sacrificed for a decreased time on block. In the present study, however, the average horizontal force was significantly higher for the kick start compared to the track start, allowing both a faster time to leave the block and higher velocity off the block. This indicated that having the kick plate allowed block time to be reduced without sacrificing horizontal impulse. The advantage of having the back foot raised and able to apply force in a more horizontal direction allows for direct
conclusIon
The results of this study indicated that the kick start on the new OSB11 start platform to be significantly faster start than the traditional track start. Prior research into swimming starts has tended to suggest that “what one does most, one does best” (Pearson et al 1998). Despite the participants own bias towards their preferred and experienced technique, the track start, the kick start was significantly faster off the block with a higher horizontal velocity and an increased on block horizontal force. This advantage was maintained through the time to 5 m and 7.5 m. Even though further research is needed into the kick start to look at the full start to 15 m, including the effect of the underwater kick and transition to stroking, it is recommended that coaches and athletes should spend time in adapting to these new blocks and this new starting technique.

REFERENCES

force application to drive the body forward with an increased horizontal velocity. The attainment of greater horizontal velocity has been seen as a benefit to overall dive performance (Galbraith et al, 2008)

There was a significantly greater horizontal velocity when leaving blocks, however this was not the case for the average velocity between 5 m and 7.5 m. This suggests that swimmers’ decelerate more from the kick start; however this should not be surprising because this was only a dive and glide study. Higher velocity leads to a larger drag force, as the drag force acting on a body moving through a fluid is proportional to the square of its velocity (Guimaraes & Hay 1985). In a start which enabled the use of kicking, the athlete may be better able to maintain a higher velocity.

The use of the dive and glide allowed for the comparison of the starts without the influence of other underwater variables such as kicking technique and the transition to stroking, however this does limit the research. Further testing of the kick start with the full dive parameters to 15m, including analysis of flight, entry and underwater movements, is needed to encompass the start as a whole.

ACKNOWLEDGMENTS
The authors would like to gratefully acknowledge the support and assistance of the AIS, Aquatics Testing, Training and Research Unit for their contribution to the testing procedure, the AIS, Technical Research Laboratory for their continued effort to produce world class equipment and the AIS, Swim team for their participation.
Kinematics Analysis of Undulatory Underwater Swimming during a Grab Start of National Level Swimmers

Houel N., Elipot M., Andree F., Hellard H.

Département Recherche Fédération Française de Natation Pôle Natation INSEP France

The aim of this study was to determine the kinematic parameters that improve performance during the underwater phase of grab starts. A three-dimensional analysis of the underwater phase of twelve swimmers of national level was conducted. Stepwise regression identified the main kinematic parameters that influence the horizontal velocity of the swimmer each 0.5 m in the range of 5 to 7.5 m. For this population of swimmers, the results enable proposition of four principles to improve the underwater phase: to be streamlined at the beginning of the underwater gliding phase, to start the dolphin kicking after 5.5 m, to have a high undulation frequency, to move like a dolphin using only feet and leg segments in underwater undulatory swimming.

Key words: Swimming starts, kinematics, undulations, underwater phase.

INTRODUCTION

In 50 and 100 m swimming races, performance has been strongly linked to start performance (Arellano et al., 1996; Mason and Cossor, 2000). Start performance is defined as the time observed between the start signal and the moment when the swimmer's head reaches 10 m (Arellano et al., 1996) or 15 m (Issurin and Verbitsky, 2002; Mason and Cossor, 2000).

The start is divided in three phases: the impulse phase on the starting block (including reaction time), the flight phase, and the underwater phase. Swimmers currently use the grab start or the track start in national and international events. The results of studies conducted since the 70s defining the most effective start remain contradictory (Issurin et al., 2002; Vilas-Boas et al., 2003). However, there is some agreement that horizontal and vertical velocity, as well as minimized hydrodynamic resistance while entering the water have a direct impact on the start performance (Arellano et al., 1996; Mason and Cossor, 2000).

The underwater phase is defined as the gliding and underwater leg propulsion (Elipot et al., 2009). When entering the water, the swimmer's velocity (around 3.61 m.s⁻¹) is greater than can be produced by underwater propulsion (Elipot et al., 2009). During the gliding phase, the streamline position (Marinho et al., 2009) influences directly the hydrodynamic resistance. Swimmer propulsive movements should ideally be initiated when the underwater velocity reaches between 2.2 and 1.9 m.s⁻¹ (Lyttle et al., 2000). Based on this result, Elipot et al. (2009) showed that the optimal beginning of the propulsive movement appeared when the swimmer centre of mass reached 5.61 to 6.01 m from the wall start. At this distance, underwater propulsion becomes more critical.

The underwater leg propulsion phase is currently termed “undulatory underwater swimming” (Arellano et al., 2006; Loebbecke et al., 2008). The undulatory underwater swimming of fish and human locomotion has been studied using an oscillating foil (Anderson et al., 1998; Read et al., 2003). These studies showed that the oscillation of the foil created a vortex wake associated with drag or thrust (Anderson et al., 1998; Read et al., 2003). Under specific conditions, an oscillating foil can vary the von Karman street of the wake and generate propulsive force or lift for manoeuvring (Anderson et al., 1998; Read et al., 2003).

These specific conditions are defined by Reynolds number, the angle of attack, the Strouhal number and the optimal phase angle between heave and pitch of the oscillating foil (Anderson et al., 1998; Read et al., 2003). The Reynolds number is defined as Re=U/ν, where U is the mean swimming velocity, ν is the characteristic length of the body and ν is the kinematic viscosity. Re represents the nature (laminar to turbulent) of the flow circulation around the body. The angle of attack α is the angle between the flow velocity and the chord of the body. The angle of attack influences directly the drag and lift coefficient (Roubou et al., 2006). The Strouhal number is a dimensionless number which represents the ratio of unsteady and steady motion defined as Str=ωA/f, where A is the maximal amplitude of the body (or heave translation) and f is the motion frequency of the oscillating body. Str is an important factor in determining propulsion forces and swimming efficiency (Anderson et al., 1998; Read et al., 2003). The phase angle ψ represents the relation between pitch and heave of the oscillating body. An optimal ψ associated to a fixed Str changes the α and influence directly the propulsion forces (Read et al., 2003). All these specific conditions can’t be easily estimated during the start underwater phase because of the decrease of the swimmers’ velocity, the modification the swimmers’ segment orientation and coordination.

The underwater area between the wall (0 m) to 10 m was recorded using three cameras (Panasonic NV-GS17 and Sony DCR-HC20E). Two cameras (camera 1, 2) were fixed behind portholes. These cameras recorded a sagittal view of the swimmers’ trajectories. The third camera was placed in a waterproof housing. This camera recorded a slanting view of the swimmer motion. The angles between the principal axis of camera 3 and the other cameras were between 60° and 70°. The underwater area was divided into two zones measuring 5X2X2 m (length, width, weight): The first zone covered the volume from the start wall to the 5 m, the second zone from the 5 m to the 10 m. Each zone was recorded by two cameras. To limits the effect of the image distortions (due to camera lens deformation) on reconstruction accuracy, only the points contained in the 2/3 centre of the camera field have been reconstructed. The cameras were positioned to minimize optical refraction effects (Snell’s law). A large distance divided the cameras and the centre of each zone (Kwon, 1999). The cameras’ optical axes were perpendicular to the air-water interface plane. Cameras were synchronised with a light flash. The video was interlaced scan and both odd and even fields were used thereby yielding an effective sampling rate of 50Hz. The gliding and undulatory underwater swimming phase was recorded from the instant when the swimmers were completely under water until the instant they began arm propulsion. To minimise errors during the digitizing process, the two sides of the swimmer’s body were assumed to be symmetric. Only the right side was digitized. Nine anatomic landmarks were identified on the swimmers with software SimiMotion (Simi Reality Motion Systems GmbH, Germany): the toe, the lateral malleolus, the knee, the iliac spine, the acromion, a finger tip, the wrist, the elbow, and the centre of the head. A modified double plane direct linear transformation method (inspired by Drenk et al., 1999) was used to calculate the landmark...
coordinates in space. Space mean reconstruction accuracy, calculated as described by Kwon & Casebolt (2006), was 6.2 mm. Data were filtered with a Butterworth II filter (Winter, 1990). Cut-off frequencies were between 5 and 7 Hz. The landmark's positions associated with Dempster's anthropometric data (1959) were used to determine the trajectory of the centre of mass. Using the coordinates of the landmarks and the centre of mass, the following variables were defined:

- time (t) of the centre of mass position,
- the horizontal velocity of the centre of mass (Vxg) and hip (Vxh);
- the angle of attack of segments trunk (αt), thigh (αth), leg (αl), foot (αf) which were defined as the angle between each segment and the velocity vector of this proximal landmarks;
- the mean kick frequency (f) of the underwater undulatory swimming or the reverse period of the ankle motion;
- the mean kick amplitude (A) or the mean peak to peak amplitude of the ankle during the underwater undulatory swimming;
- the phase time of the knee (Pk) and the ankle (Pa), that is, the time between the beginning of the hip undulatory motion and the respective distal joint (knee or ankle) undulatory motion.

These variables were calculated for each swimmer every 0.5 m between 5 m to 7.5 m. After 7.5 m, more than 40% (five swimmers) of the total number of swimmers began arm propulsion. For the range of distance, the normality of the variables was tested using Jarque-Bera Test. The effect of the independent variables (αt, αth, αl, αf, A, Pk, Pa) on the dependent variables Vxg and Vxh at each normalized distance was analysed using stepwise linear regression. The limit of significance was set as p<0.05. Time (t) at each distance was compared with Vxg and Vxh, using correlation coefficients.

RESULTS
Statistical results showed that there was a reverse correlation between Vxg and Vxh and t at each distance. The regression equation of the parameters that influence Vxg, Vxh at each distance are given in Table 1 and Table 2 with corresponding R² and p values. These results showed that different parameters influence Vxg and Vxh at different phases of the underwater undulatory swimming except at 5 m. At 5.5 m, the stepwise regression analysis showed that decrease of mean kick amplitude (A) and attack of trunk (αt) are the selected variables to improve respectively Vxg and Vxh. At 5.5, 6 and 7.5 m, the parameters that influence the horizontal velocity (Vxg and Vxh) are different for the centre of mass and the hip. Between 5.5 to 6.5 m, the stepwise regression analysis showed that the decrease of angles of attack of different segments (αt, αth, αl, αf at 6 m, αth at 6.5 m) are selected variables to improve the horizontal velocity Vxg and Vxh. Between 6 to 7.5 m increase of the phase time (Pk and Pk) was related to increasing horizontal velocity Vxg and Vxh. At 6.5 m the decrease of the angles of attack of thigh (αth) and the increase of the phase time of the knee (Pk) were related to improve horizontal velocity Vxg and Vxh (R²=0.79 for Vxg and R²=0.79 for Vxh). At 7.5 m the increase of phase time of the knee (Pk) and mean kick frequency (f) improved respectively Vxg and Vxh.

| Table 1: Regression equation with statistical coefficient and p values of independent variables which present Vxg |
|--------------------|-----------------|--------|---|
| Distance (m)       | Equation        | R²     | P values |
| 5                  | Vxg = -0.03 A   | 0.43   | 0.03 |
| 6                  | Vxg = -0.02 αth | 0.7    | 0.001 |
| 6.5                | Vxg = -0.009 αth + 1.12 Pk | 0.79 | P=0.004 |
| 7                  | Vxg = 2.29 Pk   | 0.52   | 0.017 |
| 7.5                | Vxg = 1.89 Pk   | 0.68   | P=0.01 |

Table 2: Regression equation with statistical coefficient and p values of independent variables which present Vxh

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Equation</th>
<th>R²</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Vxh = -0.02 αth</td>
<td>0.56</td>
<td>P=0.01</td>
</tr>
<tr>
<td>6</td>
<td>Vxh = -0.02 αf</td>
<td>0.7</td>
<td>P=0.001</td>
</tr>
<tr>
<td>6.5</td>
<td>Vxh = -0.019 αth + 1.12 Pk</td>
<td>0.89</td>
<td>P=0.0004</td>
</tr>
<tr>
<td>7</td>
<td>Vxh = 2.25 Pk</td>
<td>0.52</td>
<td>P=0.017</td>
</tr>
<tr>
<td>7.5</td>
<td>Vxh = 0.62 f</td>
<td>0.68</td>
<td>P=0.01</td>
</tr>
</tbody>
</table>

DISCUSSION
The inverse correlation between time of the centre of mass position and the horizontal velocity Vxg and Vxh confirm that horizontal velocity influences directly the swimmer performance (Elipot et al., 2009). The most important limitation of the result using stepwise linear regression analysis is the low number (n) of subjects to predict independent variables (k) using stepwise regression (Fonton et al., 1998). In the present study: n<3*k and k<n. For R²<0.4, the stepwise regression can only select the independent variables that present better the dependent variables. For R²>0.8, the stepwise regression presents the independent variables as best predictors and explains more that 50% of the event variability (Fonton et al., 1998). The results of the present study indicated that the swimmer should stay in a streamlined position and limit the underwater undulatory swimming before he reaches 5.5 m. At this distance, mean velocities are Vxg = 2.18 ± 0.21 m.s⁻¹ and Vxh = 2.15 ± 0.27 m.s⁻¹. This is in agreement with the previous works (Lyttle et al., 2000; Elipot et al., 2009). If the swimmer would have begun its underwater undulatory swimming too early, hydrodynamic resistances would have increased and limited the performance of the underwater phase of the start (Elipot et al., 2009). Decreasing of the angle of attack of the trunk (αt) as selected variable of Vxg, confirmed that the angles of attack directly influence drag and also lift coefficients of the body. So it has an impact on the swimming propulsion efficiency (Rouboa et al., 2006). Decreasing the angle of attack of the thigh (αth) at 6.5 m and increasing the phase time of the ankle (Pa) improves the horizontal velocity Vxg and Vxh. This result is in agreement with studies realised on fish (Loebbecke et al., 2008). For the dolphins, the propulsion minimizes the displacement of the drag producing forward parts of the body, and maximizes the displacement of the thrust producing fluke. The displacement wave that travels the length of the body also has a small magnitude along the torso, and reaches a maximum at the toes. After 7 m, the increase of the phase time of the knee (Pk) and the ankle (P) improves horizontal velocity. At 7.5 m, the mean velocities of the swimmers were Vxg = 1.76 ± 0.15 m.s⁻¹ and Vxh = 1.81 ± 0.15 m.s⁻¹, mean kick frequency (f= 2.32 ± 0.21 Hz) and mean amplitude (70.8 ± 6.04 cm) were higher than the velocity, frequency and amplitude observed in the study of Gavilan et al. (2006). The result of the stepwise regression and the comparison with the results of Gavilan et al. (2006) confirmed that the swimmer can improve his velocity with increasing frequency if he maintains large mean kick amplitude.

CONCLUSION
The stepwise regression enabled four principles to be proposed to improve the underwater phase of the swimmer: i) to be streamline with linear adjustment of the trunk and the lower body segments at the beginning of the underwater gliding phase, ii) to start the dolphin kicking after 5.5 m, with a high undulation's frequency iii) to move like dolphins using only foot and leg for propulsive segment in underwater undulatory swimming, iv) to use an optimal phase time coordination of the lower body segments to improve propulsive forces.
REFERENCES

ACKNOWLEDGEMENTS
The authors wish to thank the “Ministère de la Jeunesse, des Sports et de la Vie Associative” and the “Fédération Française de Natation” for financing this study. The authors also wish to thank Frédéric Clerc, Isabelle Amaudry and the “INSEP” for logistic support, and Jean-Lyonel Rey, Stéphane Lecat, Éric Boissière and Yves Thomasin for their contributions.
Comparison of Front Crawl Swimming Drag between Elite and Non-Elite Swimmers Using Pressure Measurement and Motion Analysis

Ichikawa, H.1, Miwa, T.1, Takeda, T.1, Takagi, H.2, Tsubakimoto, S.2

1Japan Institute of Sports Sciences, Tokyo, Japan
2University of Tsukuba, Ibaraki, Japan

The purpose of the study was to suggest a methodology to quantify the drag force during front crawl swimming and to compare the drag force between elite and non-elite swimmers. Subjects were asked to swim front crawl using arms only in a swimming flume, which set the velocity to 1.3 m/s. The pressure distribution on the swimmer’s hands and the orientation of the swimmer’s hands were measured to calculate the propulsive force. The position of the umbilicus was recorded using high speed camera with 250 fps to calculate the swimming acceleration.

Key words: drag force, propulsive force, inertial term, dynamics, front crawl swimming

INTRODUCTION

The dynamics of swimming is expressed as a mass model,

\[ m\mathbf{a} = F_{\text{gra}} + F_{\text{sta}} + F_{\text{dyn}} \]  

(1)

where \( m \) and \( \mathbf{a} \) are a swimmer’s mass and acceleration vector of the swimmer’s whole body. \( F_{\text{gra}} \) is downward force vector due to gravity, \( F_{\text{sta}} \) is upward hydrostatic force vector that is called buoyancy, and \( F_{\text{dyn}} \) is unsteady hydrodynamic force that Namashima (2006) was modelling as tangential and normal resistive fluid force, which are proportional to the local flow velocity, and inertial force due to added mass, which is proportional to the local flow acceleration. The component on the swimming direction of Equation 1 was expressed as,

\[ \mathbf{a} = F_{\text{dyn-swim}} = F_{\text{p}} + F_{\text{d}} \]  

(2)

where \( a \) and \( F_{\text{dy-swim}} \) are the component along with swimming direction of \( \mathbf{a} \) and \( F_{\text{dy}}, \) respectively. The \( F_{\text{dy-swim}} \) is separated into forward force \( F_{\text{p}} \), which is propulsive force, and backward force \( F_{\text{d}} \), which is drag force.

Many researchers have suggested some methodologies to quantify the drag force in swimming as “active drag”, although it is difficult to quantify the drag force in swimming (Di Prampero et al. 1974, Clarys et al. 1974, Hollander et al. 1986, Kolmogorov et al. 1992). The methodologies have some assumptions, such as “swimming velocity is constant” (Di Prampero et al. 1974, Hollander et al. 1986), “propulsive and drag force are in balance” (Clarys et al. 1974, Kolmogorov et al. 1992). Almost all previous researchers expressed the drag force as a single value, which was a mean value during some strokes. The drag force is, however, changing from moment to moment during swimming, so the assumptions and the expression of drag force would make us overlook some information of swimming dynamics. It is important to observe the dynamics of the propulsive and drag forces during swimming quantitatively and continuously, because it would lead to better discussion of the swimming technique and performance.

In the present study, the drag force, which is changing during front crawl swimming, was quantified with a methodology that is according to the equation of motion (Eq.2) to discuss the dynamics of front crawl swimming. The purposes of the study were to suggest a methodology to quantify the drag force during front crawl swimming, and to compare the drag force between an elite (a competitive swimmer) and a non-elite (a triathlete) swimmer.

METHODS

The subjects were a well-trained male competitive swimmer and a male triathlete. The profile of the subjects is shown in Table 1. The subjects were asked to swim the front crawl using arms only in a swimming flume, which was set the flowing velocity at 1.3 m/s. In the experiment, the pressure distribution on swimmer’s hands, the orientation of the hands and the position of the umbilicus were measured during the trial.

Table 1. Characteristics of the subjects.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Height [m]</th>
<th>Weight [kg]</th>
<th>Age [yrs]</th>
<th>Best record for 100m-Fr. [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitive swimmer</td>
<td>1.79</td>
<td>74.0</td>
<td>22.4</td>
<td>49.6</td>
</tr>
<tr>
<td>Triathlete</td>
<td>1.70</td>
<td>68.0</td>
<td>22.7</td>
<td>82.0</td>
</tr>
</tbody>
</table>

Twelve small pressure sensors, 6 mm diameter and 0.7 mm thick, were attached on the swimmer’s both hands. The attaching positions were the palmar and dorsal sides at the metacarpophalangeal (MP) II joint, the middle point of MP III and IV joints, and MP V joint (Fig. 1). The pressure values were recorded at 500Hz to calculate the hydrodynamic force \( F_{\text{hand}} \) exerted on the swimmer’s hands using the following equation,

\[ F_{\text{hand}} = A_{\text{hand}} \sum_{i} w_i (p_{\text{palm}} - p_{\text{dorsum}}) \]  

Eq.3,

where \( A_{\text{hand}} \) was the plane area of the hand. The index \( i \) indicates a position to attach the pressure sensor, that is \( i = 1 \) is MP II joint, 2 is the midpoint of MP III and IV joints and 3 is MP V joint. The \( p_{\text{palm}} \) and \( p_{\text{dorsum}} \) were the measured pressure on the palmar and dorsal sides of the hand, respectively. The \( w_i \) is the weight of divided area on the each sensor’s position, and it was defined as \( w_i = w_1 = 0.25 \) and \( w_3 = 0.5 \) in the present study. And it was assumed that the direction of the hydrodynamic force on a hand was perpendicular to plane of the hand.

Figure 1. A photograph of a pressure sensor (top) and the positions to be attached the pressure sensors on the palmar and dorsal sides of a left hand (bottom). The sensors were also attached on the right hand of the swimmer in a similar position as the illustration.
To calculate the orientation of the both hands during underwater phase, the visual markers were attached on the tip of the 1st, 3rd and 5th fingers and the wrist of the swimmer. The swimming flume used in the experiment has windows at the bottom and the left side of a swimmer. Four synchronized cameras (TK-C1461, Victor, Japan) were set on to register motion of the swimmer’s hands through the windows. Each visual marker on the video was digitized manually at a frequency of 60 field/second using a digitizing software (Video Annotator for Excel, JISS, Japan) and the three dimensional coordinates were calculated using 3D-DLT method using a computational software (Mathematica 7, Wolfram Research, USA). The orientation of the hands was expressed as the normal vector of the hand plane, which was calculated by the method of least squares with the 3-D coordinates of the four markers on the hand.

One other visual marker, fixed on the umbilicus, was used as an alternative point to the centre of gravity. The movement of the marker was recorded by a high speed camera (Fastcam-pci, Photron, Japan) with 250 fps from the bottom view. The positions were digitized manually and calibrated it along with swimming direction only using the referred software (Video Annotator for Excel and Mathematica).

The component on the swimming direction of the hydrodynamic force \( F_{\text{hand}} \) on each hand was calculated using the normal vector of the hand. It was defined that the propulsive force \( F_p \) was the summation of the components of the left and right hands. The swimming acceleration \( a \) was calculated as the second-order derivative of the position of the umbilicus with respect to time. The inertial term \( ma \) was defined as the product of the swimming acceleration and the swimmer’s mass. The estimation of the drag force \( F_d \) was based on the equation of motion Eq.2, so the drag force was obtained as the difference of the inertial term \( ma \) and the propulsive force \( F_p \) (Fig. 2). Note that the obtained \( F_p \) in the present study was backward force and would be expressed as negative value.

The coefficient of drag \( C_d \) was calculated in each trial using the following equation,

\[
C_d = \frac{2F_d}{\rho A_{\text{whole}}V^2} \quad \text{Eq.4,}
\]

where \( \rho \) was density of water, and \( V \) was the mean swimming velocity, which was 1.3 m/s. The \( A_{\text{whole}} \) was the swimmer’s surface area, which was calculated by the Shitara’s formula for Japanese male,

\[
A_{\text{whole}} = 105.29 \times (H \times 100)^{0.619} \times W^{0.460} / 10^4 \quad \text{Eq.5,}
\]

where \( H \) and \( W \) were the swimmer’s height and weight, respectively (Shitara et al. 2009). To discuss validity of the drag force \( F_d \) obtained by our methodology, the coefficient of drag \( C_d \) was compared with the reported values (Takagi et al. 1998).

RESULTS

The inertial term, propulsive and drag force during 5 seconds were obtained in each subject (Fig. 3). The mean drag forces were 21.3 N in the competitive swimmer and 50.3 N in the triathlete, respectively. It was observed that the competitive swimmer had phases of no propulsive force. On the other hand, the triathlete kept producing propulsive force with high stroke frequency. To compare the drag estimated in the present study with that of previous studies, the mean and absolute values of Reynolds numbers and coefficient of drag were calculated and plotted in same plane with the reported values (Takagi et al. 1998) in Fig. 4.

DISCUSSION

It seemed that it would be difficult for the triathlete to maintain the instructed swimming velocity, which was 1.3 m/s. The Fig. 3 demonstrated the reason was the larger drag force. The drag force of the triathlete reached 150 N. It must be noted that the drag force was expressed as negative value in the Fig. 3, although it was less than 100 N in the competitive swimmer. To overcome the larger drag force and to maintain the velocity, the triathlete had to keep producing the propulsive force with high stroke frequency without a break. As a result, the triathlete’s effectiveness of swimming could be lower. It was not so large de-acceleration of the competitive swimmer, although he had phases of no propulsive force (Fig. 3). It was because the drag force was not so large in the phases. The lower drag force would provide him effective swimming.

The validity of the obtained drag force in the methodology deserves more discussion. The comparison of the coefficient of drag with the previous researches in the Fig. 4 showed that the obtained values would be lower in some degree. It was observed that the drag force was positive value in every in-sweep phases of the both subjects (Fig. 3), although the drag force should be negative value, which meant backward force, in the definition of the Equation 2. In this study, the drag force was calculated as the difference between the measured inertial term and propulsive force. The positive drag force resulted from the smaller propulsive force than the inertial term. It was assumed that the propulsive force was exerted by the hands only and that the direction of the hydrodynamic force on the hand was perpendicular to plane of the hands. However, there are possibilities that any segments additional to the hands, especially the forearms, contribute to produce forward force. It seemed that the hy...
CONCLUSION

In the comparison of the dynamics during front crawl swimming between the elite swimmer (competitive swimmer) and the non-elite swimmer (triathlete), it was suggested that the drag force would affect the performance of swimming strongly. The methodology in the present study provides us information on the dynamics, such as the inertial term (swimming acceleration), the propulsive force and the drag force, during front crawl swimming, although the accuracy of the measurement needs to be improved. In conclusion, it can be stated that the observation of the parameters changing from moment to moment would be useful to compare the dynamics between the elite swimmer and the non-elite swimmer and discuss the technique of swimming.

REFERENCES


Whole Body Observation and Visualized Motion Analysis of Swimming

Ito, S.¹, Okuno, K.²

¹Kogakuin University, Tokyo, ²Waseda University, Tokyo

It is an advantage to film a swimmer's whole body in order to understand the swimmer's technique. However, it is difficult to understand details, such as twisting arms or stroke paths. Equipment was constructed which provides a continuous image of swimming motions by blending underwater and overwater images with a video mixer. Underwater and overwater images were taken by cameras loaded onto a cart placed on a poolside track. The view from above the swimmer was observed by an overhanging camera to observe wave resistance. In order to grasp detailed swimming motions, logger data were synchronized with the actual motion images. Wavelet transformation, a chronological frequency analysis, was also performed on these logger data and the dominant frequency was viewed chronologically with different swimming styles.

Key words: observation, visualization, motion analysis, wavelet transform

INTRODUCTION

Swimming is the successive motion of propulsive and recovery movements in the water. Analysis of the swimming motion can be provided to swimmers and coaches for improvement of performance. It is important to understand the underwater motion in order to improve swimming technique. Tracking underwater cameras are often used in competition but are not generally used in training because of their installation and cost. Barbosa et al. (2006) were able to produce a continuous image of the swimming movements by blending underwater and overwater images with a video mixer. Ito (2003) has also developed the same equipment and can capture the swimmer's whole body motion including recovery overwater. Both underwater and overwater images were recorded by the cameras loaded onto a cart placed on a poolside rail track. The view from above the swimmer including the waves generated around the swimmer could not be seen in this recording. In order to compensate for this defect, a view from above the swimmer was recorded, to consider wave resistance.

It is still difficult to observe detailed movement, such as twisting arms underwater. In order to observe these detailed motions of the forearm in swimming, Ohgi (2006) captured 3D accelerations and 3D angular velocities by a data logger and analyzed change in movement caused by fatigue. However, no actual motion images were used in analyzing their data.

In this study, a whole body swimming image including a view from above, was taken and also synchronizing the three-dimensional acceleration and the angular velocity data on the forearm and analyzed them to understand subtle differences in S-shaped and I-shaped movements in free style. A chronological dominant frequency was obtained by using wavelet transformation in these obtained data.

METHODS

The experiments were performed in a 50m x 25m indoor swimming pool. The subject of the experiments was an elite breast stroke swimmer who had won a gold medal in 4 x 100m medley relay in Universiade Belgrade 2009. The observation equipment consisted of underwater and overwater cameras in a frame installed on a cart placed on a metal pipe track. A crane tripod with a camera above the swimmer was installed on the same cart. The underwater and over water images were synthesized into a whole body image by a video mixer. The image taken from above the swimmer was inserted into the video mixer image using 4 image dividers.
Fig. 1 Data logger of motion sensors

Figure 1 shows a data logger of motion sensors which has 3 accelerometer components, 3 gyroscopic components, a depth sensor and a propeller system speedometer built-in (PD3G3Gy made by Leonard Little company). It has a cylindrical shape of diameter φ 23mm and length of 235mm and is composed of a CPU, 256MB memory, and 8 A/D converter components. The data logger can measure 8 hours continuously in 128Hz. The data logger was set on the backside of the left forearm on a three-dimensional coordinate axis as shown in Fig.2. Data were sampled at 128Hzd, that is, almost 300000 datum in one hour. The three-dimensional acceleration and the angular velocity data taken from the data logger and corresponding to swimming movements, were extracted with Igor ProVer.6 of the Waveometric Co. Ltd. These wave data were synchronized with the swimming motion images by Pixel Runner of Tellus Image Co. Ltd. by matching the motion image with the arm entering the water and the peak point of the data waves.

Fig. 2 Definition of 3-components on data logger

Regarding the logger signal processing, the wavelet transformation was analyzed by using free macro software of Ethographer (Sakamoto et al., 2009) on Igor Pro. Wavelet transformation is one of the techniques of the chronological frequency analysis. The Morlet function of 15 cycles was employed as the mother wavelet in this study. A key advantage over Fourier transformation is temporal resolution. In addition, wavelet transformation captures both frequency and location information.

RESULTS and DISCUSSION

Figure 3 shows the composite underwater and overwater image of the swimming motion obtained by the observation equipment. The picture appears as if the swimmer had been observed in a water tank through a window. Figure 3 also shows the three-dimensional accelerations and the angular velocity obtained by the data logger attached on the forearm synchronized with the motion image. In the case of the breaststroke shown in Fig. 3, a sequence of opening and closing motion of the arms appeared in Arm Slide in Fig. 3-1. Concerning the acceleration of Arm Extension in Fig.3-2, two peaks were seen in each stroke, although the motion of the arm itself was carried out smoothly. Since the accelerometer has also gathered gravitational acceleration, the negative peak was obtained when the arm was moving downward. The effect of gravitational acceleration was seen well in the acceleration of Arm Pull in Fig.3-3. The complex 3 component angular velocity of arm Pitch, Roll, and Yaw is shown in Fig.3-5, 6, 7 respectively.

In order to understand these data better, synchronizing this motion image and the data waves was a very effective mean to grasp the differences in details of an individual swimmer’s strokes even in the same swimming style.
The graph at the top of Fig. 4 shows the transition of flexion/extension motion of the forearm described with angular velocity. The graph in the middle indicates the wavelet transformation for the same data and the graph at the bottom shows the transition of depth. Each of them was acquired with the sensor attached on the forearm in the freestyle stroke. Comparing the graphs at the top and the bottom, the angular velocity in the stroke phase is almost constant, while that in the recovery phase decreased rapidly. The Fourier transformation converts a spectrum space of a certain period into a frequency space. On the other hand, the wavelet transformation is the time series data of the momentary frequency conversion in the same time space. In other words the Fourier transformation is less useful in analyzing non-stationary data, where there is no repetition within the region sampled. The wavelet transformation allows the components of a non-stationary signal to be analyzed better. In the middle of Fig. 4, the thick striped pattern appears in the dominant cycle for about 2 seconds of the respective movements. The output of wavelet transformation can be sliced in x and y directions. Figure 5(a) and 5(b) are the sections of Fig. 4 at Time A and B respectively. These sliced sections show momentary cycle (=1/frequency) analyses. In these figures, the primary peak indicates the stroke cycle. The secondary peak appears in the cycle of S-shaped stroke. Figure 6 shows cycle sliced section data of wavelet transformation output at Slice Section C in Fig. 4 in Cycle 2.2 sec. This is a stroke cycle of freestyle in this case. The bottom peak shows the turn phase.

Thus, the wavelet transformation converts motion waves to pattern designs. Three acceleration waves and three angular velocity waves acquired with a motion logger indicate six motion patterns. The four swimming styles freestyle, breaststroke, backstroke and butterfly stroke, consist of 24 pattern pictures. The difference of picture patterns should lead to another motion analysis with wavelet transform. Figure 7 shows the transition of flexion/extension motion of the forearm described with angular velocity, the wavelet transform for the same data and the transition of depth in the butterfly stroke. Two stripe patterns appear in the wavelet transform picture. Each stripe shows the basic stroke cycle and the cycle of a keyhole shaped stroke in the butterfly stroke.

CONCLUSIONS
The motion filming equipment was developed to show the whole body, in a synthesized swimming image of the underwater and overwater motion. Furthermore, this synthesized swimming image was synchronized with the data obtained with the data logger which samples the 3D acceleration and 3D angular velocity of the forearm movement.

Wavelet transformation was performed on the motion data and the various motions were visualized as a new motion analysis method. As implied by the wavelet transformation, it should be possible to express the difference in the strokes even in the same event or to express a collapse of technique by fatigue by showing the motion as picture patterns.
A Full Body Computational Fluid Dynamic Analysis of the Freestyle Stroke of a Previous Sprint Freestyle World Record Holder

Keys, M.; Lyttle, A.; Blanksby, B.A. & Cheng, L.

1 The University of Western Australia, Australia
2 Western Australian Institute of Sport, Australia

Computational Fluid Dynamics (CFD) allows simulation of complex fluid flow regimes and geometry. A case-study examined propulsive and drag forces experienced across the body during full-body freestyle swimming using CFD. An elite male swimmer was scanned using a whole body 3D scanner and manual digitising provided the 3D freestyle kinematics to animate the model. A Finite Volume Method of CFD modelling was used which incorporated a realisable K-ε turbulence model. The CFD analysis enabled an examination of the forces distributed across the body throughout the full freestyle stroke. This project increases the level of foundational knowledge and presents practical points that may improve swimming performance.

Key words: Computational Fluid Dynamics; Freestyle; Drag; Propulsion

INTRODUCTION

Typically, current techniques of elite swimmers are derived from a mix of natural genetics, feel for the water, knowledge of experienced coaches, and trial and error methods. Although this is considered to be effective, little is known of the hydrodynamic factors making one technique faster than another.

It is widely accepted that an increased understanding of fluid flow patterns in swimming should enhance performance. However, it is very difficult to quantify the relative effects of these flow patterns experimentally when swimming with, at best, only approximations of total body effects being provided. To date, research has incorporated one or more of the following methods to estimate the drag/propulsion effects and flow patterns:

- Physical testing using either force plates, drag lines or towing devices.
- Analysis and numerical modelling of recorded flow lines and vortex patterns measured by injecting dye or Particle Image Velocimetry (PIV) methods, based on swimmers in a test pool or swimming flume.
- Entirely numerical modelling which use estimations of drag and inertia effects on shapes similar to those of human limbs.

Each method provided valuable information and some empirical data concerning a few of the questions raised. However, inherent limitations exist and fluid flows around an irregularly shaped human form that is always changing in shape and position, are highly complex. Hence, none of these techniques can provide a full understanding of what is actually occurring throughout a full swimming stroke cycle.

Computational Fluid Dynamics (CFD) can be used to model and solve complex problems of fluid flow and is ideally suited to analysing drag and propulsion across the body when swimming. Based on fundamental fluid mechanics principles, CFD allows complex fluid flow regimes and geometry to be simulated, providing visualization of the resulting variables across the entire solution domain. This can provide insights into problems thus far unobtainable via known physical testing techniques. To date, CFD predictions of forces acting on a swimmer have been limited to passive drag studies (Bixler et al., 2007), hand motion through the water (Bixler & Riewald, 2001; Sato & Hino, 2002) and underwater kicking (Lyttle et al., 2006; Von Loebbecke et al., 2009).

The current study was the culmination of several years spent developing a full body stroking CFD model. The objective was to examine the distribution of forces across the human body for an elite sprint freestyler. A better understanding of the interaction of propulsive and drag forces across the body will increase the foundational knowledge of swimming hydrodynamics.

METHODS

A CFD case-study examined the propulsion and drag forces across the body during a full freestyle swimming stroke. At the time of the kinematic recordings, the swimmer used held both the 50m and 100m freestyle World Records. Therefore the technique examined was highly evolved.

The 3D kinematics recorded one full stroke cycle with a separate above- and below-water camera used on each side of the swimmer. Each camera was pointed at 45-60° to the horizontal plane. The swimmer performed regular freestyle at race pace and a full 3D kinematic analysis was performed using manual video digitizing. Medial and lateral body landmarks, rather than joint centres, were digitized for each body segment to allow for calculating full segment rotations. Cartesian coordinates for the derived joint centres were then converted to a polar coordinate system.

A full 3D surface scan of the swimmer provided accurate 3D geometry for the CFD simulations. The laser scanning of the swimmer was performed using a Cyberware WBX whole body laser scanner, with a density of one point every 4mm. Higher resolution scans were also conducted of the hands, head and feet (density of one point every 0.67mm).

The higher resolution scans were then aligned and merged seamlessly into the full body scan to provide more accuracy at these locations (see Figure 1). The 3D model was then processed to extract 288 non-uniform rational b-splines (NURBS), curved surfaces forming a 3D solid model of the swimmers.

The computer simulation was performed using the CFD software package “FLUENT” (version 6.3.26; Fluent Inc., Lebanon, NH) which utilizes the Finite Volume Method of CFD modelling. A realizable K-ε turbulence model, together with a multi-phase fluid domain, was used with standard wall functions to simulate the boundary layer. This was combined with the use of prism cells near the wall boundaries and tetrahedral cells in the main fluid domain. The domain surfaces contained varying mesh densities to define the detail around highly curved areas while still maintaining a workable mesh size. The surface mesh on the swimmer comprised approximately 100000 triangular surface elements with the total simulation consisting of close to 5 million cells (see Figure 1 for sample triangulated meshing surrounding the hand).

Figure 1. 3D laser scanned image of the subject (top) and sample triangulated mesh surrounding the hand (bottom).
RESULTS

Results below detail the forces on individual body segments throughout the full freestyle stroke. For a summary of momentum changes of the rigid (body segments) and flexible (joints) body parts, see Table 1. The full freestyle stroke was analysed over a cycle time of 1.04s. Momentum values were reported as a means of comparing between different cycle times and relative body weights. These momentum changes were then averaged to a per-second value to enable comparison with previous studies. Figure 2 displays the resultant forces over the entire body throughout the stroke cycle, and Table 2 outlines the temporal points associated with critical events in the stroke cycle. The swimmer’s velocity was between 1.9m.s⁻¹ and 2.3m.s⁻¹, with the average over this cycle being 2.08m.s⁻¹.

Table 1. The momentum (Ns) changes per second in the swimmer from the full freestyle stroke simulation over one full stroke cycle.

<table>
<thead>
<tr>
<th>Time</th>
<th>Description</th>
<th>Momentum (Ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total per cycle</td>
<td>31.23</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>30.03</td>
</tr>
<tr>
<td></td>
<td>Hand</td>
<td>23.80</td>
</tr>
<tr>
<td></td>
<td>Wrist</td>
<td>11.12</td>
</tr>
<tr>
<td></td>
<td>Forearm</td>
<td>9.92</td>
</tr>
<tr>
<td></td>
<td>Elbow</td>
<td>6.56</td>
</tr>
<tr>
<td></td>
<td>Upper Arm</td>
<td>6.23</td>
</tr>
<tr>
<td></td>
<td>Shoulder</td>
<td>-17.20</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>-10.18</td>
</tr>
<tr>
<td></td>
<td>Neck</td>
<td>-0.37</td>
</tr>
<tr>
<td></td>
<td>Upper Trunk</td>
<td>-37.94</td>
</tr>
<tr>
<td></td>
<td>Mid Trunk</td>
<td>-24.74</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>3.18</td>
</tr>
<tr>
<td></td>
<td>Hips</td>
<td>-7.41</td>
</tr>
<tr>
<td></td>
<td>Thighs</td>
<td>18.28</td>
</tr>
<tr>
<td></td>
<td>Knees</td>
<td>9.41</td>
</tr>
<tr>
<td></td>
<td>Lower Leg</td>
<td>27.39</td>
</tr>
<tr>
<td></td>
<td>Ankle</td>
<td>-1.91</td>
</tr>
<tr>
<td></td>
<td>Feet</td>
<td>20.34</td>
</tr>
<tr>
<td></td>
<td>Combined Arms</td>
<td>33.98</td>
</tr>
<tr>
<td></td>
<td>Combined Legs</td>
<td>66.10</td>
</tr>
<tr>
<td></td>
<td>Trunk and Head</td>
<td>-70.05</td>
</tr>
</tbody>
</table>

* per second

DISCUSSION

The race analysis of the swimmer used in this study from his 50m Freestyle final at the 2008 Australian Olympic Trials (final time - 21.28sec) revealed that the free swimming component made up over 87% of total race time. Thus, major benefits will accrue if this swimmer can improve technique during the stroking phases. To date, no studies have successfully examined propulsive and drag forces across the total body while swimming. This information is crucial in order to optimise swimming technique.

Examining the breakdown of force distributions revealed that the arms and legs create significant amounts of propulsion, with the trunk contributing the majority of the drag. The hands provided a total propulsive momentum of 23.8Ns; while the combined contributions of the wrist, forearm and elbow were 27.6Ns. This highlights that the forearm position during the underwater arm stroke was as critical as that of the hands. The head contributed less drag than the upper and lower trunk components. That could be because it is occasionally positioned in only a semi-submerged state, and that the lesser volume influences the potential amount of wave drag experienced. The thighs, knees and lower legs also contributed greater percentages of propulsion than the feet. This also reinforces the importance of entire leg movements and positioning, rather than just focusing on the feet positioning. However, this may be due to the feet coming out of the water regularly, and the possibility of wave assistance.

The overall changes in forces throughout the stroke were characterized by six clear cycles, containing four small peaks and two large peaks. These peaks represent the six beat kick pattern that was adopted. The two large peaks correlated with the peak propulsion of the left and right arm strokes; and occurred simultaneously with two of the kick cycles. These peaks, particularly those associated with the arm stroke propulsion, were reflected by increases in the swimmer’s instantaneous velocity. The two highest velocity peaks occurred just after the peak propulsive forces, namely at 0.64s and 1.14s, when the swimmer’s velocity surged to 2.3m.s⁻¹.

The initial review of the individual arm force profiles confirmed the observations detailed in the overall drag and propulsion review. There
was a definite peak associated with the left and right arms as they moved through the cycle. The left arm peak occurred at 0.55s and the right at 1.07s. There was a secondary, lower peak that occurred prior to these, at 0.33s for the left, and 0.89s for the right arms.

The first phase was with the arm out in front of the head and appeared to create an equal amount of drag for both arms of around -34N to -38N; and lasted for between 0.09 and 0.11s. This is due to the drag resulting from placing the arm into a zone of high moving water. The hand was seen as the first point to start accelerating out of this extended position when it begins to move at around 0.18s. This is followed by the initial acceleration phase where the swimmer pushes out laterally from the body and rapidly accelerates the hands and forearms; with a peak force in this phase of between 50N and 100N. The force is governed initially by accelerating the forearm and hand, and then slowly transitions towards being more velocity based. The right hand had a 15% greater acceleration and velocity in this phase, which partially explains the slightly greater forces generated at this time.

The third phase appears to be a transition from the swimmer pushing outwards by using mostly lateral muscles, and then begins to pull inwards towards the midline of the body. The simulation showed considerable deceleration by the forearm and hands at this point, and was probably the reason for the decreased propulsion. Results indicated that keeping this section of the pull-through at high acceleration and high velocity would help improve the overall stroke technique.

The fourth phase was the main power pulling section of the stroke, and achieved peak propulsive forces between 260N and 340N. It should be noted that this peak force does not occur at either the peak acceleration or velocity, of the hand or forearm. It also appears to occur just after the swimmer exposes the best angle of the hand and forearm at 90º to the direction of travel (see Figure 3). The swimmer's peak instantaneous velocity occurring just after this point substantiates that this force is a true peak.

The fifth phase is the section where the arm exits the water and is almost a point where drag is suddenly created. This could result from the arm decelerating as it approaches the end of the stroke, or, also may be due to some of the wave formation effects. The sixth phase is the recovery where each arm, in turn, is out of the water.

**CONCLUSION**

The current study provided insight into how propulsion and drag forces are generated throughout a full freestyle swimming stroke through the use of CFD analysis. The resultant outcome of the analysis is both an increased level of foundational knowledge related to the production of propulsion and drag forces, as well as the provision of practical points that may be used to improve freestyle performance.

**REFERENCES**


An Analysis of an Underwater Turn for Butterfly and Breaststroke

Kishimoto, T.1, Takeda, T.2, Sugimoto, S.1, Tsubakimoto, S.2 and Takagi, H.3

1Edogawa School for the Disabled, Tokyo, Japan
2University of Tsukuba, Ibaraki, Japan
3National Agency for the Advancement Sports and Health, Tokyo, Japan

The purpose of this study was to analyze selected characteristics of the "Apnea Turn", a new underwater turn and to compare this turn with the conventional "Open Turn". The subjects were ten elite competitive butterflyers and breaststrokers. The 5 m Round Trip Time (5 m-RTT) of the Apnea turn was faster than the Open turn (5.55±0.27 s and 5.62±0.33 s). While the times of the into turn phase and out of turn phase of 5 m-RTT for the Apnea turn were faster than the Open turn, the time of the pivot phase was significantly slower than the Open turn. The push off velocity of the Apnea turn was significantly higher than the Open turn. The 5 m Round Trip Time (5 m-RTT) of the Apnea turn was faster than the Open turn (5.55±0.27 s and 5.62±0.33 s). While the times of the into turn phase and out of turn phase of 5 m-RTT for the Apnea turn were faster than the Open turn, the time of the pivot phase was significantly slower than the Open turn. The push off velocity of the Apnea turn was significantly higher than the Open turn (3.02±0.11 m·s⁻¹ vs. 2.92±0.06 m·s⁻¹). These results suggest that the Apnea turn may improve swimming performance and may be a prospective new turning method.

Key words: Underwater turn, elite swimmers, round trip time, swimming performance

INTRODUCTION

The "Open Turn" (Maglischo 2003) is commonly used in competitive swimming with most swimmers turning near the surface to breathe after touching the wall with their hands, especially in the butterfly and breaststroke (Colwin 2002). However, it actually causes an increase in the wave resistance in the vicinity of the water surface before and after pushing from the wall, and may decrease speed. Therefore, turning underwater may enhance performance by reducing resistance.

The present study examined an "Apnea Turn" that is carried out with the whole body under water during the pivot operation and push from the wall. This method may decrease the wave drag by pivoting underwater. A verification of performance improvement was carried out to clarify the characteristics of the Apnea turn and to consider its possibility as a new turning method for competitive swimmers.

METHOD

The subjects were ten elite competitive swimmers whose specialties were butterfly and breaststroke. Their age, height and weight were 21.1±1.2 years, 176.3±6.2 cm and 68.7±6.5 kg, respectively. Two trials were performed for both the Open turn and Apnea turn. The best attempts were analyzed. The subjects swam from 10 m and turning after the subjects were asked to exert the maximum performance. This study conformed to the competitive regulations, ie 1) touching both hands to the wall, 2) remaining always on the front. All participants provided an informed consent and all procedures were approved by the institutional review board.

Figure 1 shows the placement of the cameras. This study used two sets of underwater and over water simultaneous recording video camera systems, and another underwater camera to record the subjects for analysis (60Hz). To obtain the 2D position coordinates, we used the "FrameDias version" and "AviUtil99" for two dimension motion analysis.

FIGURE 1 Camera placement for three dimensional analysis

Figure 2 also shows the camera placement from above. The 5 m RTT was considered as the 1) total time from the 5 m point to touching the wall, 2) time of pivot phase (from touching the wall to pushing off the wall, 3) time from pushing off the wall to the 5 m point and also the calculated values of 4) the velocity of the turn-in phase (swimming velocity from the 5 m point to the 2.5 m point), 5) the velocity of approach phase (swimming velocity from the 2.5 m point to touching the wall), 6) the velocity of the glide phase (swimming velocity from the wall to the 2.5 m point), and 7) the velocity of turn-out phase (swimming velocity from the 2.5 m point to the 5 m point).

FIGURE 2 The design of turning phase in this study

The definition of indexes during the push off phase in this study is shown in figure 3. We calculated 1) the "push off velocity", the velocity of the swimmer's center of gravity (CG) when the swimmer's feet leave the wall, 2) the vertical component of the "push off velocity", 3) the horizontal component of the "push off velocity", 4) the distance between the wall and the CG when the swimmer's feet touch the wall and 5) the distance between the water surface and the CG when the swimmer's feet touch the wall.

FIGURE 3 Definition of push off the wall in this study

The SPSS statistics processing software (11.5J) were used for statistical analysis. The t-test was used to determine significant differences between the two trials, the pearson's correlation analysis was performed to discuss relationships between indexes. p<0.05 was considered statistically significant.
RESULTS
Table 1 shows a comparison between swimming velocities and the times of each phase. The average 5 m RTT was 5.62±0.33 s for the Open turn, and 5.55±0.27 s for the Apnea turn. There was no significant difference between the two turns but the 5 m RTT for the Apnea was shorter than for the Open turn for six of the 10 subjects. The mean times of the turn-in phase and turn-out for the Apnea turn was significantly shorter than the Open turn but the pivot phase for the Apnea turn was significantly longer than the Open turn (p<0.01). The swimming velocities were higher following the Apnea turn than the Open turn. The mean values of the swimming velocities following an Apnea turn were higher than the Open turn for the turn in phase (p<0.01), approach phase (p<0.01), glide phase (p<0.01), and turn out phase (p<0.05).

Table 1 Comparison between the swimming velocity and time of each phase

<table>
<thead>
<tr>
<th>Unit</th>
<th>Open Turn</th>
<th>Apnea Turn</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>The time of turn-in</td>
<td>s</td>
<td>2.60±0.25</td>
<td>2.51±0.21</td>
</tr>
<tr>
<td>The time of pivot</td>
<td>s</td>
<td>0.99±0.09</td>
<td>1.05±0.07</td>
</tr>
<tr>
<td>The time of turn-out</td>
<td>s</td>
<td>2.02±0.13</td>
<td>1.98±0.10</td>
</tr>
<tr>
<td>5m Round Trip Time</td>
<td>s</td>
<td>5.62±0.33</td>
<td>5.55±0.27</td>
</tr>
<tr>
<td>The velocity of turn-in</td>
<td>m·s⁻¹</td>
<td>1.55±0.16</td>
<td>1.58±0.14</td>
</tr>
<tr>
<td>The velocity of approach</td>
<td>m·s⁻¹</td>
<td>1.33±0.14</td>
<td>1.35±0.11</td>
</tr>
<tr>
<td>The velocity of glide</td>
<td>m·s⁻¹</td>
<td>2.41±0.11</td>
<td>2.52±0.07</td>
</tr>
<tr>
<td>The velocity of turn-out</td>
<td>m·s⁻¹</td>
<td>1.78±0.15</td>
<td>1.81±0.13</td>
</tr>
</tbody>
</table>

** (p<0.01) * (p<0.05)

Table 2 shows the analysis of the push off phase. A mean value of the push off velocity was 2.92±0.06 m·s⁻¹ during the Open turn, and 3.02±0.11 m·s⁻¹ during the Apnea turn, with the push off velocity in the Apnea turn significantly higher than the Open turn (p<0.01). The distance between the wall and the CG in the Apnea turn was significantly closer than the Open turn (p<0.01). The position of the CG when the swimmer’s feet touch the wall for the Apnea turn was also significantly closer than the Open turn (p<0.01). The position of the center of gravity when the feet leave the wall was deeper than the Open turn. At the higher swimming velocity such as over 2.0 m·s⁻¹ in the start phase and turn phase, it is necessary to go submerge to 0.4 m to 0.6 m below the surface (Lyttle 1999). With the Apnea turn it is possible to push off the wall straight and strongly by bending the knees more, thus the swimmer can travel through the optimal depth, and higher velocities were acquired after pushing from the wall. The Apnea turn has the possibility to contribute to swimming performance. However, the time of the pivot phase for the Apnea turn was slower than the Open turn significantly (p<0.01), so there is still room for improvement. The greater time for the pivot phase might arise, for example, from lack of experience or simply because the movement is entirely under water. However, if the swimmer can become familiar with the motion and reduce the drag, the Apnea turn could improve the performance of the competitive race.

CONCLUSION
The aim of this study was to investigate the Apnea turn and its potential as a new turning method. The following findings were obtained: 1) The Apnea turn has a significantly higher velocity and faster time than the Open turn in each phase except the pivoting action. 2) The Apnea turn can accomplish a higher push off velocity from the wall. 3) There may still be room for improvement in the pivot phase because of lack of experience. These results reveal that the Apnea turn has the possibility to improve swimming performance. However, only a comparison for the time and velocity in the turning phase has been conducted in this study. It is necessary in the future to also investigate the effect on the entire race distance.

REFERENCES

DISCUSSION
The Apnea turn was faster than the Open turn for all phases. Especially, the higher velocity of the glide phase and the turn-out phase for the Apnea turn attributed to the time and the velocity of the push off phase. If a swimmer can exert a high push off velocity, and transfer it to the stroke phase efficiently, keeping this higher velocity, it would improve overall performance. To exert the highest possible push off velocity from the wall, it is important that the push off angle is as close to horizontal as possible (Goya 2001) and the distance between the wall and the CG of a swimmer is closer to the wall (Chollet 2002, Lyttle 1999). Also, the position of the center of gravity for the Apnea turn when the feet leave the wall was deeper than the Open turn. At the higher swimming velocity as over 2.0 m·s⁻¹ in the start phase and turn phase, it is necessary to go submerge to 0.4 m to 0.6 m below the surface (Lyttle 1999). With the Apnea turn it is possible to push off the wall straight and strongly by bending the knees more, thus the swimmer can travel through the optimal depth, and higher velocities were acquired after pushing from the wall. The Apnea turn has the possibility to contribute to swimming performance. However, the time of the pivot phase for the Apnea turn was slower than the Open turn significantly (p<0.01), so there is still room for improvement. The greater time for the pivot phase might arise, for example, from lack of experience or simply because the movement is entirely under water. However, if the swimmer can become familiar with the motion and reduce the drag, the Apnea turn could improve the performance of the competitive race.
Mechanical and Propulsive Efficiency of Swimmers in Different Zones of Energy Supply

Kolmogorov, S.V.¹,², Vorontsova, A.R.², Rumyantseva, O.A.¹, Kochergin, A.B.³

¹Pomer State University, Arkhangelsk, Russia
²All-Russian Swimming Federation, Moscow, Russia
³All-Russian Swimming Federation, Moscow, Russia

Dimensionless coefficients for mechanical and propulsive efficiency (eₚₑ and eᶠₑ) have been studied using physiological and biomechanical methods in swimming various strokes. The research has been conducted in the three zones of energy supply: below the threshold of anaerobic metabolism (AT), above the zone of maximal oxygen consumption (VO₂ max) and in the zone between AT and VO₂ max. The highest values of eₚₑ and eᶠₑ for male and female swimmers have been revealed in the zone between AT and VO₂ max. In all the three zones of energy supply the values of eₚₑ are higher for male swimmers. At the same time the values of eᶠₑ are equal for male and female swimmers.

Key words: Metabolic and mechanical power, efficiency, velocity

INTRODUCTION

Development of efficient technologies to train swimmers assumes solving of an important theoretical and practical problem of interdependence between energy supply, on the one hand, and swimming biomechanics, on the other one. In case of biological objects' steady non-stationary motion in water, at the first stage metabolic energy is transformed with losses into mechanical one, which at the second stage is transformed with additional losses into useful activity result, i.e. into swimming velocity. To describe precisely basic mechanisms of the phenomenon under study, this process of human swimming was formalised in form of mathematic model (Kolmogorov, 1997):

\[ v_0 = \frac{P_{\text{AT}} \times e_{\text{p}} \times e_{\text{p}} \times F \times v}{f 	imes d} \]  

(1)

in which \( v_0 \) is mean swimming velocity at the competition or training distance (m/s); \( P_{\text{AT}} \) is power of active energetic metabolism (W); \( e_{\text{p}} \) is dimensionless coefficient of mechanical efficiency, i.e. ratio of total external mechanical power (\( P_{\text{E}} \)) to \( P_{\text{AT}} \); \( e_{\text{f}} \) is dimensionless coefficient of propulsive efficiency, i.e. ratio of useful external mechanical power (\( P_{\text{E}_{\text{F}}(\text{d})} \)) to \( P_{\text{AT}} \); \( F \) is frontal component of active drag force (N).

Hence, the goal of this research has been to investigate experimentally regularities of metabolic energy transformation into swimming velocity at different zones of energy supply on the basis of equation 1.

METHODS

The research was conducted at the period of spring training mesocycle lasting from January to April. Twenty-nine university swimmers (15 female subjects aged from 17 to 22 and 14 male subjects aged from 18 to 23) took part in the research. Correct studying of regularities of metabolic energy transformation into useful activity result is possible only in conditions when character and direction of training load carried out by the subjects during the training mesocycle, are taken into consideration. Therefore, the time of experimental investigation of this process in the three different zones of energy supply was coordinated with certain periods of purposeful technical and functional training. It is this circumstance that explains the order of tests.

In February the first test was conducted in the zone of energy supply below the threshold of anaerobic metabolism (AT). Test 1 was carried out in a swimming pool on the basis of training series of 8×200 m by the subjects during the training mesocycle, are taken into consideration. Therefore, the time of experimental investigation of this process in the three different zones of energy supply was coordinated with certain periods of purposeful technical and functional training. It is this circumstance that explains the order of tests.

In March the second test was conducted in the zone of energy supply above the maximal oxygen consumption (VO₂ max). Test 2 was carried out in the flume, with per-limiting metabolic power being applied in swimming by the basic stroke. The work lasted one minute for sprinters and two minutes for medium distance swimmers.

In April the third test was conducted in the zone of energy supply between AT and VO₂ max. Test 3 was carried out in the flume in the course of training series of 3×1 minutes (for sprinters) and 3×2 minutes (for medium distance swimmers) by basic stroke, intervals of work and rest being altered as 1:1.

Preliminary, individual swimming velocities in all the three zones of energy supply were calculated for each subject on the basis of special tests in the swimming pool.

To define experimentally variables in equation 1, a complex of physiological and biomechanical research methods was applied.

The power of active energetic metabolism (\( P_{\text{AT}} \)) in all the three tests was calculated as a ratio of energetic expenditures at the test distance (\( E, J \)) to work time at this distance (\( t, s \)). Energetic expenditures were defined experimentally by the method of indirect calorimetry. For this purpose, all necessary gaseous parameters of the ventilation air were measured with the help of the mobile system “MetaMax” and lactic acid concentration was determined in capillary blood before and after the test. When the research was conducted in the swimming pool (test № 1), gas analytical measurements were taken during rest breaks between training distances. When the research was conducted in the flume (tests № 2 and № 3), gas analytical measurements were taken before, during and after the test. All experimental results were reduced to conditions of STPD. Quantitative values of \( E \) were calculated on the basis of special equations (Capelli et al., 1998; Zamparo et al., 1999), which correspond entirely to the three studied zones of energetic supply and are described in detail in the specified papers.

Total external mechanical power (\( P_{\text{E}} \)), frontonal component of active drag force (\( F_{\text{F}(\text{d})} \)) and useful external mechanical power (\( P_{\text{E}_{\text{F}}(\text{d})} \)) were defined using a biodymanic method (Kolmogorov, 2008), which consists of a complex of independent biomechanical and hydrodynamic methods to measure necessary physical values. At first, total external mechanical power (\( P_{\text{E}_{\text{AT}}} \)) was defined by the method of small perturbations at the maximal swimming velocity (\( v_{0_{\text{max}}} \)) (Kolmogorov et al., 1997). Afterwards, the corresponding value of \( P_{\text{E}_{\text{AT}}} \) was calculated for every experimental swimming velocity in the studied zones of energetic metabolism (\( v_{0_{\text{exp}}} \)) on the basis of the well-known (Troussant and Truijens, 2005) and verified experimentally dependence between these parameters (Kolmogorov and Koukoyakin, 2001):

\[ P_{\text{E}_{\text{AT}}} = P_{\text{E}_{\text{AT}}} \times v_{0_{\text{max}}} \times v_{0_{\text{exp}}} \]  

(2)

The frontal component of active drag force under conditions of swimmer’s steady non-stationary forward motion (\( F_{\text{F}(\text{d})} \)) was defined experimentally for every experimental swimming velocity (\( v_{0_{\text{exp}}} \)), using the corresponding hydrodynamic method (oriented specially to measure this physical value) (Kolmogorov, 2008). This paper describes in detail the theory, necessary mathematic models and practical technology to define \( F_{\text{F}(\text{d})} \) within the whole range of \( v_{0_{\text{exp}}} \) relevant for the research.

Useful external mechanical power (\( P_{\text{F}} \)) was defined from the following equation:

\[ P_{\text{F}} = F_{\text{F}(\text{d})} \times v_{0_{\text{exp}}} \]  

(3)

When the parameters, indicated above, were defined for every experimental swimming velocity in the studied zones of energetic metabolism (\( v_{0_{\text{exp}}} \)), dimensionless coefficients of mechanical (\( e_{\text{p}} = P_{\text{E}_{\text{F}}} / P_{\text{E}_{\text{AT}}} \)) and propulsive (\( e_{\text{f}} = P_{\text{F}} / P_{\text{E}_{\text{F}}} \)) efficiency were calculated.

RESULTS

Tables 1 and 2 represent experimental results of the studied process in dolphin swimming by a female subject and in brass by a male subject, correspondingly. These tables give only key parameters of \( P_{\text{AT}} \times e_{\text{p}} \times e_{\text{f}} \times F_{\text{F}(\text{d})} \) and \( v_{0_{\text{exp}}} \) which are necessary to solve quantitatively equation (1) and...
which express entirely the transformation process of metabolic energy into useful activity result in human swimming. All intermediate values are omitted to concentrate attention on the studied process. The values of subjects' body length (L) and body mass (m) functionally connected with \( P_{ei} \) and \( F_{ei(d)} \) are given for the moment of experimental period ending, since the range of their variations was insignificant.

Table 1. Experimental values of active energetic metabolism power and efficiency of its transformation into swimming velocity in the studied zones of energy supply in dolphin swimming by a sprinter female subject (\( L = 1.73 \text{ m}, m_0 = 60.1 \text{ kg} \)).

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_{ei} ) W</td>
<td>below ( AT )</td>
<td>above ( \text{VO}<em>2</em>{\text{max}} ) between ( AT ) and ( \text{VO}<em>2</em>{\text{max}} )</td>
<td></td>
</tr>
<tr>
<td>( e_i )</td>
<td>0.062</td>
<td>0.061</td>
<td>0.068</td>
</tr>
<tr>
<td>( e_p )</td>
<td>0.655</td>
<td>0.649</td>
<td>0.714</td>
</tr>
<tr>
<td>( F_{ei(d)} ) N</td>
<td>25.20</td>
<td>46.90</td>
<td>39.50</td>
</tr>
<tr>
<td>( \text{VO}<em>2</em>{\text{max}} \text{ m}^{-1} )</td>
<td>1.30</td>
<td>1.50</td>
<td>1.44</td>
</tr>
</tbody>
</table>

Table 2. Experimental values of active energetic metabolism power and efficiency of its transformation into swimming velocity in the studied zones of energy supply in brass swimming by a medium distances male subject (\( L = 1.90 \text{ m}, m_0 = 76.0 \text{ kg} \)).

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_{ei} ) W</td>
<td>below ( AT )</td>
<td>above ( \text{VO}<em>2</em>{\text{max}} ) between ( AT ) and ( \text{VO}<em>2</em>{\text{max}} )</td>
<td></td>
</tr>
<tr>
<td>( e_i )</td>
<td>0.073</td>
<td>0.066</td>
<td>0.076</td>
</tr>
<tr>
<td>( e_p )</td>
<td>0.714</td>
<td>0.693</td>
<td>0.752</td>
</tr>
<tr>
<td>( F_{ei(d)} ) N</td>
<td>42.57</td>
<td>65.79</td>
<td>58.05</td>
</tr>
<tr>
<td>( \text{VO}<em>2</em>{\text{max}} \text{ m}^{-1} )</td>
<td>1.22</td>
<td>1.46</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Table 3 represents mean group values of mechanical and propulsive efficiency for female and male subjects, who took part in this research, in the studied zones of energy supply. The matter is that the frontal component of active drag force depends essentially on a swimming stroke, whereas power of active energetic metabolism in all the studied zones of energy supply depends on human body mass. Therefore, the summarising Table 3 includes only the values of \( e_i \) and \( e_p \), which reflect integrally efficiency of metabolic energy transformation process into useful activity result in human swimming.

Table 3. Dimensionless coefficients of mechanical (\( e_i \)) and propulsive (\( e_p \)) efficiency in the studied zones of energy supply for female and male subjects (\( P \) is the level of differences significance).

<table>
<thead>
<tr>
<th>Test</th>
<th>Women</th>
<th>P</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e_i )</td>
<td>below ( AT )</td>
<td>0.060±0.0018</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>between 1 and 2</td>
<td>0.647±0.009</td>
<td>0.670±0.010</td>
</tr>
<tr>
<td>( e_p )</td>
<td>above ( \text{VO}<em>2</em>{\text{max}} )</td>
<td>0.059±0.0022</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>between 2 and 3</td>
<td>0.656±0.008</td>
<td>0.675±0.009</td>
</tr>
<tr>
<td>( e_i )</td>
<td>below ( \text{AT} ) and ( \text{VO}<em>2</em>{\text{max}} )</td>
<td>&lt;0.05</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>between 1 and 3</td>
<td>&lt;0.001</td>
<td>0.05</td>
</tr>
<tr>
<td>( e_p )</td>
<td>Test 3</td>
<td>0.065±0.0015</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>( \text{VO}<em>2</em>{\text{max}} \text{ m}^{-1} )</td>
<td>0.704±0.009</td>
<td>0.721±0.012</td>
</tr>
</tbody>
</table>

DISCUSSION

Analysis of the results presented in Table 1 shows regular increase of \( P_{ei} \) by 124.5% in the zone of energy supply above \( \text{VO}_2_{\text{max}} \) (test 2) and by 40.0% in the zone of energy supply between \( AT \) and \( \text{VO}_2_{\text{max}} \) (test 3) in comparison with the aerobic zone of energy supply (test 1). At the same time such increase of \( P_{ei} \) brings to essentially smaller increase of swimming velocity (by 15.4% and 10.8% correspondingly). A combination of the effective training programme and the purposeful application of special exercises aimed at increasing of propulsive efficiency allows the subject to reach the highest values of \( e_i \) and \( e_p \) during the whole experimental period in the zone of energy supply between \( AT \) and \( \text{VO}_2_{\text{max}} \) (test 3).

Analysis of the results presented in Table 2 allowed revealing another tendency. Comparing to the aerobic zone of energy supply (test 1), the subject also showed increased \( P_{ei} \) by 114.6% in the zone of energy supply above \( \text{VO}_2_{\text{max}} \) (test 2) and by 45.0% in the zone of energy supply between \( AT \) and \( \text{VO}_2_{\text{max}} \) (test 3). Such increase of \( P_{ei} \) also brings to essentially smaller increase of swimming velocity (by 19.7% and 16.4% correspondingly). At the same time the values of subject's \( e_i \) and \( e_p \) are the smallest in the zone of energy supply above \( \text{VO}_2_{\text{max}} \) (test 2) and the highest in the zone of energy supply between \( AT \) and \( \text{VO}_2_{\text{max}} \) (test 3). As expected, the male subject's \( P_{ei} \) and \( e_i \) are essentially higher than the female's one.

In the aerobic zone, the zone between \( AT \) and \( \text{VO}_2_{\text{max}} \) is the most effective in all swimming strokes for male swimmers becomes regularly higher as the zones of energy supply are applied from the first to the last. The values of \( P_{ei} \) have essential individual variations connected with weight, sex and level of subjects' current functional preparedness. At the same time, the dynamics of individual values of \( P_{ei} \) during the training season don't play such a great role for swimming velocity increase, as it was supposed earlier.

Swimming velocity increases in all the studied zones of energy supply during the training mesocycle mainly due to rising of \( e_i \) and \( e_p \), as \( P_{ei} \) insignificantly increases or stays the same in the corresponding zone of energy supply. Essential rising of losses at both stages of energy transformation in any zone of energy supply during the training season is a negative phenomenon, which can cause breaking of adaptation processes in a human organism. Interpreting experimental results of the studied process, it's necessary to take into account the dominating value of the zone of energy supply, within the limits of which subject's basic competitive activity is carried out.

Analysis of the results presented in Table 3 shows that male subjects have higher coefficients of mechanical efficiency (\( e_i \)) in all the studied zones of energy supply, which is connected with a higher level of their force preparedness. This fact was repeatedly recorded earlier in analogous researches at bicycle ergometer (Utkin, 1993). Subjects of both sexes have the highest values of \( e_p \) in the zone of energy supply between \( AT \) and \( \text{VO}_2_{\text{max}} \).

The values of propulsive efficiency in all swimming strokes for male and female subjects don't differ from each other, which agree with experimental data obtained earlier in freestyle (Toussaint, 1988). No difference of this parameter for male and female swimmers was also indicated by Zamparo (2006), though quantitative values of \( e_p \) presented in the article are essentially smaller. The maximal values of \( e_p \) are registered in the zone of energy supply between \( AT \) and \( \text{VO}_2_{\text{max}} \). It is natural, that these highest values of \( e_p \) in the specified zone are positively influenced by the time of measurement, the closest to the condition of sports form. This fact, revealed experimentally, is of principle theoretic and practical significance, since it demonstrates entirely the essence of the contemporary conception of swimmers' training. Besides, the obtained values of \( e_p \) verify explicitly the statement how important it is to choose an optimal individual combination between the length and the frequency of swimming motions cycle to gain the highest sports result (Craig and Pendergast, 1979).

In human's water locomotion, mechanical efficiency (\( e_p \)) is much lower than propulsive efficiency (\( e_i \)), which is connected with regularities of metabolic energy transformation into mechanical one at the first stage.
CONCLUSION
Effective and safe ways to improve swimmers’ sports results in the process of training mesocycle are, first of all, connected with decreasing of unavoidable losses at both stages of metabolic energy transformation into useful activity result, which is quantitatively reflected in dynamics of values of mechanical and propulsive efficiency.

REFERENCES

Prediction of Propulsive Force Exerted by the Hand in Swimming
Kudo, S. 1 and Lee, M.K. 1

1Republic Polytechnic, Singapore

The aim of this study was to develop a method to predict propulsive forces exerted by the hand in swimming based on the pressure distribution on the hand. Hydrodynamic forces acting on the hand were predicted using 12 pressure sensors, and the hand direction was determined by a motion capture system. We combined information to predict the propulsive forces exerted by the hand during the front crawl stroke. The proportion of drag and lift forces relative to the propulsive forces was 55% and 45%, respectively. The best-fit equations used to predict hydrodynamic forces in a previous study may cause errors in the prediction of hydrodynamic forces acting on the hand due to multicollinearity. Such errors can be minimized with a lesser order of best-fit equations. In addition, feedback on the propulsive forces exerted by the hand can be generated within a few hours.

Key words: pressure, hand kinematics, drag, lift.

INTRODUCTION
Propulsive force exerted by the hand and hydrodynamic forces acting on the hand in swimming have been quantified and used to analyze the technique of swimming strokes (Cappaert et al., 1995; Schleihauf et al., 1983; Schleihauf et al., 1988). However, the method to predict hydrodynamic forces acting on the hand could involve considerable errors as the effect of hand acceleration and wave drag acting on the model have not been taken into consideration in previous studies on the prediction of hydrodynamic forces acting on the hand (Pai and Hay, 1988; Kudo et al., 2008). Acceleration using a hand model has been taken into account in linear motion (Sanders, 1999). Errors in the prediction of hydrodynamic forces on the hand could also result from the time consuming method of manual digitization of landmarks on the swimmer’s hand from recorded image taken from multiple points of view (Payton and Bartlett, 1995; Lauder et al., 2001).

A pressure method was developed to predict hydrodynamic forces acting on the hand in swimming based on the pressure at 12 points of the hand surface (Kudo et al., 2008). The study measured hydrodynamic forces acting on a hand model and pressures on the model surface so as to develop a best-fit equation to predict hydrodynamic forces acting on the model. However, a method to predict propulsive forces exerted by the swimmer’s hand using the pressure method during swimming has not been developed. Propulsive forces by the hand are useful information for both swimmer and coach in the analysis of technique in swimming. Thus, the aim of this study was to develop a method to predict propulsive forces exerted by the hand using the pressure method during swimming. This study also considered the hand size of a swimmer in a best-fit equation because the hand size of a swimmer can be different from the size of a hand model used in the previous study.

METHODS
A swimmer whose hand size was 0.0136 m² was asked to swim the front crawl stroke at sub-maximal effort for 18 m in the swimming pool at Republic Polytechnic following some light warm up. A right-handed Cartesian coordinate system was embedded at the bottom of the pool; the x-direction defined the direction of swimming, the y-direction defined the side-to-side direction, and the z-direction defined the vertical direction.

A portable data logger with 12 pressure sensors (MMT, Japan) was...
developed to measure pressure on the hand and to predict hydrodynamic forces acting on the hand during swimming. The data logger was attached on the back of the swimmer, and twelve pressure sensors were attached on the swimmer’s hand according to Kudo et al. (2008). An underwater motion capture system using eight cameras (Qualisys, Sweden) was used to acquire kinematic data of the hand during swimming. Three reflective markers were attached on the right hand, the third fingertip, trapezium and pisiform bone. The data logger and the motion capture system were synchronized, and the signals were recorded at 100 Hz. The signals of data logger and motion capture system for a right hand stoke were smoothed using a fourth order, zero lag, low-pass Butterworth filter (Winter, 1990). Static pressures due to the hand depth during swimming were taken into account based on the marker data so as to predict hydrodynamic forces (drag and lift forces) acting on the hand by the pressure method (Kudo et al., 2008).

The present study constructed a new best-fit equation using a dependent value which hydrodynamic forces acting on the hand model divided by the size of the hand model used in the previous study (Kudo et al., 2008), taking into consideration the hand size of a swimmer. Thus, the magnitude of hydrodynamic forces acting on the swimmer’s hand was predicted by multiplying the predicted values from the best-fit equations by the hand size of a swimmer (Loetz et al., 1988; Takagi and Wilson, 1999). For constructing the best-fit equations in the present study, hydrodynamic forces were decomposed into the three directions in the local reference hand-centric system; a direction parallel to the longitudinal axis of the hand (x-axis), a direction perpendicular to the plane of hand motion in the two consecutive frames (y-axis), a direction perpendicular to the z- and x-axes (y-axis). Using kinematic data from the motion capture system the directions of drag and lift forces, the angle of attack (AP) and sweepback angle (SB) were computed. Propulsive forces exerted by the hand during swimming were computed using the hand kinematics and hydrodynamic forces on the swimmer’s hand.

The best-fit equations used to predict hydrodynamic forces acting on the hand model by the pressure method in the previous study consisted of 12 regression coefficients and higher order polynomials. The number of regression coefficients was up to 36. Therefore, there might be a considerable effect of multicollinearity on the prediction (Kutner et al., 2004). Different order of best-fit equations, including the order of best-fit equation from the pressure method in the previous study (B-Eq1) and the first order of best-fit equations (B-Eq2), were used to predict hydrodynamic forces acting on the swimmer’s hand to check the effect of multicollinearity on the prediction. In addition, the variance inflation factor (VIF) was computed to quantify the effect of multicollinearity.

RESULTS

Mean propulsive forces exerted by the hand predicted by B-Eq1 over a stroke was 15 ± 11 N. Mean propulsive forces exerted by the hand predicted by B-Eq2 over a stroke was 33 ± 24 N, and the maximum value of propulsive force was 77 N (Figure 1). The contribution of drag and lift forces to propulsive force predicted by B-Eq2 was 55% and 45%, respectively. Mean hand speed over a stroke was 2.3 ± 0.3 ms⁻¹ and maximum hand speed was 2.7 ms⁻¹. The angle of attack (AP) changed from 24° to 85°, and the sweepback angle (SB) changed from 73° to 254° over a stroke.

Mean values of VIF were 12.86 ± 7.05 for the first-order polynomial equations with the 12 sets of pressure, 39.28 ± 32.50 for the second-order polynomial equations with the pressure sets, and 196.10 ± 298.10 for the third-order polynomial equations with the pressure sets.

DISCUSSION

This study developed a method to predict propulsive forces exerted by the hand in swimming. Feedback on propulsive forces exerted by the hand predicted can be provided to the swimmer and coach within a few hours by combining the pressure method with kinematic data from the motion capture system. Additionally, the contribution of drag and lift forces to propulsion by the hand can be provided to help swimmers and coaches in the analysis of stroke technique to improve swimming performance.

The mean of hydrodynamic forces acting on the hand predicted by the best-fit equation in the previous study (B-Eq1) was different from that by B-Eq2. The mean of VIF changed considerably among the three different orders of best-fit question. The results mean that multicollinearity might affect the predicted values. A maximum VIF value in excess of 10 indicates that multicollinearity may influence the least square estimates of regression coefficients (Kutner et al., 2004). The values of correlation coefficient were 0.69 in propulsions predicted by B-Eq1 and B-Eq2, 0.79 in propulsions from drag forces predicted by the two best-fit equations, and 0.88 in propulsions from lift forces predicted by the two best-fit equations. The results indicate that the trend of the prediction is similar in the two equations. Based on the VIF values B-Eq2 may be better to predict hydrodynamic forces acting on the hand during swimming. The erroneous effect on the prediction of hydrodynamic forces acting on the hand during swimming can be detected using the information on the magnitude of hydrodynamic forces acting on the hand, kinematics of hand, as well as AP and SB. Further study is necessary to validate the pressure method to predict propulsive forces exerted by the hand during swimming especially for the magnitude of hydrodynamic force predicted.

The present study showed that a swimmer is able to generate propulsive forces by the hand in the down-sweep phase between 20 and 40 frames (Figures 1 and 2). The majority of propulsion resulted from lift forces. During the down-sweep phase, drag force by the hand did not have substantial contribution to propulsive force because the hand was still moving forward. The swimmer in this study did not incorporate sideway sweep of the hand in the inward sweep phase between 40 and 60 frames (Figure 2). Thus, the contribution of lift forces to propulsive forces was small (Figure 1). Propulsive forces from lift forces exerted by the swimmer’s hand can be increased if the swimmer performed further inward sweep. The gaps of the hand trajectories in the xy-plane between 40 and 60 frames were large and the trajectories moved backwards, indicating that the hand moved backwards with large velocities (Figure 2). Therefore, propulsive forces from drag forces reached the maximum value (69 N) between 40 and 60 frames that is 90% of propulsive forces by the hand (Figure 1). Berger et al. (1999) reported mean propulsive forces exerted by the hand in the front crawl stroke of 21 N among nine swimmers at a mean swimming velocity of 1.15 ms⁻¹. Berger et al. (1999) and Schlehauf et al. (1983) showed that a swimmer attained maximum propulsion of approximately 100 N by the hand. The propulsive forces in this study were not considerably different from the two previous studies.
The difference can be due to a skill level of a swimmer. The subject in this study was a recreational swimmer while the subjects in the two previous studies were competitive swimmers of international or national standard. Also, the different values of propulsive forces among three studies can be due to the different method to predict hydrodynamic forces acting on the hand during swimming.

Figure 2. Hand trajectories in the fixed pool-centric reference system. The three-dimensional coordinates of hand was obtained by taking the midpoint of the finger tip and the point between trapezium and pisiform. I = frame 20; II = frame 40; III = frame 60.

REFERENCES


Arm Coordination, Active Drag and Propelling Efficiency in Front Crawl

Seifert, L. 1, Schnitzler, C. 1,2, Alberty, M. 3, Chollet, D. 4, Toussaint, H.M. 4

1 CETAPS EA 3832, Faculty of Sports Sciences, University of Rouen, France
2 Faculty of Sports Sciences, Strasbourg Marc Bloch University, France
3 LEMH EA 3608, Faculty of Sports Sciences, University of Lille, France
4 Move Institute, Frie University, Amsterdam, The Netherlands

Active drag, regularity and Index of Coordination (IdC) all increase with speed in front crawl swimming, but the link between these parameters remains unclear. The aim of this study was thus to examine the relationships between the index of coordination (IdC) and propelling efficiency ($e_p$) and the active drag ($D$). Thirteen national level male swimmers completed two incremental speed tests swimming front crawl with arms only in free condition and using a Measurement of Active Drag (MAD) system. The results showed that inter-arm coordination was linked to active drag and not propelling efficiency.

Key words: Biomechanics, motor control, efficiency

INTRODUCTION

Swimming speed results from the interaction of propulsive and resistive forces. However, as the swimmer’s hand lacks a fixed push of point to propel the body forward, mechanical power applied by the hand in the water is wasted in kinetic energy imparted to the water ($P_k$). Thus the total mechanical power out-put ($P_m$) is the sum of the kinetic power ($P_k$) and power delivered to overcome drag force ($P_d$). Toussaint et al. (2006) defined the propelling efficiency ($e_p$) as the ratio between $P_d$ and $P_m$. The question remains how the inter-arm coordination in front crawl can be organised to have the highest $e_p$? For example, does superposition mode of coordination, in comparison to catch-up mode, relates to a higher $e_p$? Indeed, in superposition mode the total propelling force is shared by the two hands (for a brief moment in time) and it looks like force is generated with a double hand-surface. Previously, Toussaint et al. (1991) demonstrated that using paddles $e_p$ increases by 7.8%.

Chollet et al. (2000) proposed the Index of Coordination (IdC) to quantify the lag time, continuity or superposition between the propulsive actions of the two arms. These authors observed that IdC changed from catch-up (IdC<0%) to superposition (IdC>0%) mode when the swimmers increased their speed from the 800-m race pace to 100-m race pace. Examining eight race paces (from 1500-m to maximal speed), Seifert et al. (2007b) noted that above a critical value of IdC<0% to superposition (IdC>0%), $e_p$ increases by 7.8%. If assumed that during all-out 25-m sprints, $P_o$ was maximal and, equal on the MAD-system and in the free condition, propelling efficiency ($e_p$) could be calculated as:

$$e_p = P_d / P_m$$

For the free swimming condition, two underwater video cameras filmed from frontal and side views at 50Hz. They were connected to a double-entry audio-visual mixer, a video timer, a video recorder and a monitoring screen to mix and genlock the frontal and lateral views on the same screen, from which the mean stroke rate was calculated. A third camera, mixed with the side view for time synchronisation, filmed all trials with a profile view from above the pool. This camera measured the time over the 12.5-m distance (from 10-m to 22.5-m) to obtain the velocity. Stroke length was calculated from the mean speed and stroke rate values. From the video device, three operators analysed the key points of each arm phase with a blind technique, i.e. without knowing the analyses of the other two operators. Each arm stroke was broken into four phases: entry and catch of the hand in the water, pull, push and recovery. The duration of the propulsive phases was the sum of pull and push phases and that of the non-propulsive phases was the sum of entry and recovery phases. Arm coordination was quantified using the index of coordination (IdC) as defined by Chollet et al. (2000). The IdC represented the lag time between the propulsive phases of each arm. The mean IdC, which was calculated from three complete strokes, was expressed as a percentage of the mean stroke duration. When there was a lag time between the propulsive phases of each arm, the stroke coordination was in “catch-up” (IdC<0%). IdC<0% indicated that the arms were in “opposition” and IdC<0% corresponded to the “superposition” of the propulsive phases of both arms. According to Seifert and Chollet (2009) quadratic regression was calculated to model the relationships between IdC and speed.

METHODS

Thirteen national male front crawl swimmers (mean age: 21.5±3.9yr, mean height: 185.5±5.2cm, mean weight: 80.5±7.8kg, time on 100-m front crawl: 53.4±3.2, years of practice: 11.8±3.5) performed two intermittent graded speed tests in randomised order, using an arms-only front crawl stroke (using a pull-buoy): one on the MAD-system (10 bouts of 25-m) and one in the free swimming condition (8 bouts of 25-m), from slow (~60%) to 100% of maximal speed (with an absolute increment of 0.05 m·s⁻¹, which corresponded to a relative increment of 5% of maximal speed). The bout was self-paced to avoid the speed variations that can arise when the swimmer follows a target. To be sure that the normalized $v$ (expressed in % of maximal speed) on the MAD-system and in free swimming condition were close for each bout, two more bouts were allowed on the MAD-system as this condition was uncommon for the swimmers. Four minutes of rest were given before the next bout was swum.

For the MAD-system condition, the swimmers swum by pushing off from fixed pads with each stroke. These push-off pads were attached to a 22-m rod and the distance between them was 1.35 m. The rod was mounted 0.8 m below the water surface and was connected to a force transducer, enabling direct measurement of push-off forces for each stroke. Assuming a constant mean swimming speed, the mean propelling force equals the mean drag force (D in N). Hence, swimming one bout on the system yields one data-point for the speed-drag curve. Following the equation $D = K \cdot v^3$, the relationship between drag force and speed was established for each swimmer and thus the individual $K$ factor and coefficient were determined. According to Toussaint et al. (2006), while swimmers swim on the MAD-system, propulsion is generated without wasting kinetic energy ($P_o$) and consequently all $P_o$ of can be used to overcome drag. Thus, $P_o$ equals $P_d$. Knowing that, $P_o = D \cdot v$, $P_o = K \cdot v^3$. If assumed that during all-out 25-m sprints, $P_o$ was maximal and, equal on the MAD-system and in the free condition, propelling efficiency ($e_p$) could be calculated as:

$$e_p = P_d / P_m = K \cdot v^{3/2} / v^{3/2}$$

For the free swimming condition, two underwater video cameras filmed from frontal and side views at 50Hz. They were connected to a double-entry audio-visual mixer, a video timer, a video recorder and a monitoring screen to mix and genlock the frontal and lateral views on the same screen, from which the mean stroke rate was calculated. A third camera, mixed with the side view for time synchronisation, filmed all trials with a profile view from above the pool. This camera measured the time over the 12.5-m distance (from 10-m to 22.5-m) to obtain the velocity. Stroke length was calculated from the mean speed and stroke rate values. From the video device, three operators analysed the key points of each arm phase with a blind technique, i.e. without knowing the analyses of the other two operators. Each arm stroke was broken into four phases: entry and catch of the hand in the water, pull, push and recovery. The duration of the propulsive phases was the sum of pull and push phases and that of the non-propulsive phases was the sum of entry and recovery phases. Arm coordination was quantified using the index of coordination (IdC) as defined by Chollet et al. (2000). The IdC represented the lag time between the propulsive phases of each arm. The mean IdC, which was calculated from three complete strokes, was expressed as a percentage of the mean stroke duration. When there was a lag time between the propulsive phases of each arm, the stroke coordination was in "catch-up" (IdC<0%). IdC<0% indicated that the arms were in "opposition" and IdC<0% corresponded to the "superposition" of the propulsive phases of both arms. According to Seifert and Chollet (2009) quadratic regression was calculated to model the relationships between IdC and speed.
Assuming that during all-out 25-m sprints, $P_c$ was maximal and equal in the MAD-system and in the free condition, $\varepsilon_p$ for each swimmer was calculated. Pearson correlation was assessed between $\varepsilon_p$ and IdC for the maximal swimming condition. An ANOVA analysed the effect of bouts of 25-m on IdC and D. Quadratic regression between IdC and $v$ in the free condition and a power regression between $D$ and $v$ in the MAD-system condition were established for each swimmer; then, the average equation for the whole sample of swimmers was calculated. If assumed that during all-out 25-m sprints, $P_c$ was maximal and equal both on the MAD-system and in the free condition, it was also assumed that the effort was equal when swimming bout 1 at 60% of maximal speed on the MAD-system and bout 1 at 60% of maximal speed in the free condition (and so on for bout 2 at 65% of maximal speed, then bout 3 at 70% of maximal speed). Regressions between IdC and $D$ were established for each swimmer, after which the average equation for the whole sample of swimmers was calculated. For all tests, the level of significance was set at 95% ($p<0.05$).

RESULTS
The average value of $\varepsilon_p$ was 0.55±0.11 and ranged between 0.34 and 0.79, while average IdC was -0.9±2.8% that corresponded to an opposition coordination mode (Table 1); IdC values ranged between -5.1% to 3.6%, supporting that swimmers used various modes of arm coordination when they swim at maximal speed. There was no significant correlation between IdC and $\varepsilon_p$, IdC and $v$ while $\varepsilon_p$ was positively correlated to $v$ ($r=0.68; p<0.05$).

Table 1. $v$ values on MAD-system and in free condition, $\varepsilon_p$ and IdC during maximal speed on 25-m sprint for the thirteen swimmers.

<table>
<thead>
<tr>
<th>Subject</th>
<th>$v_{\text{MAD}}$ (m·s$^{-1}$)</th>
<th>$v_{\text{free}}$ (m·s$^{-1}$)</th>
<th>$\varepsilon_p$</th>
<th>IdC</th>
</tr>
</thead>
<tbody>
<tr>
<td>BJ</td>
<td>1.89</td>
<td>1.53</td>
<td>0.53</td>
<td>-0.9</td>
</tr>
<tr>
<td>BS</td>
<td>2.05</td>
<td>1.43</td>
<td>0.34</td>
<td>-2.9</td>
</tr>
<tr>
<td>BS</td>
<td>1.90</td>
<td>1.55</td>
<td>0.54</td>
<td>-5.1</td>
</tr>
<tr>
<td>CVD</td>
<td>1.72</td>
<td>1.53</td>
<td>0.70</td>
<td>-0.3</td>
</tr>
<tr>
<td>JFJ</td>
<td>1.88</td>
<td>1.53</td>
<td>0.54</td>
<td>-0.6</td>
</tr>
<tr>
<td>JG</td>
<td>1.95</td>
<td>1.56</td>
<td>0.51</td>
<td>-1.1</td>
</tr>
<tr>
<td>MT</td>
<td>1.69</td>
<td>1.43</td>
<td>0.61</td>
<td>-4.0</td>
</tr>
<tr>
<td>MN</td>
<td>1.72</td>
<td>1.41</td>
<td>0.55</td>
<td>3.6</td>
</tr>
<tr>
<td>MA</td>
<td>1.78</td>
<td>1.39</td>
<td>0.47</td>
<td>2.7</td>
</tr>
<tr>
<td>MB</td>
<td>1.88</td>
<td>1.56</td>
<td>0.58</td>
<td>-0.1</td>
</tr>
<tr>
<td>MK</td>
<td>1.93</td>
<td>1.54</td>
<td>0.51</td>
<td>-2.9</td>
</tr>
<tr>
<td>TK</td>
<td>1.91</td>
<td>1.49</td>
<td>0.48</td>
<td>-3.1</td>
</tr>
<tr>
<td>SJ</td>
<td>1.95</td>
<td>1.80</td>
<td>0.79</td>
<td>3.3</td>
</tr>
<tr>
<td>Mean</td>
<td>1.87</td>
<td>1.52</td>
<td>0.55</td>
<td>-0.9</td>
</tr>
<tr>
<td>SD</td>
<td>0.11</td>
<td>0.10</td>
<td>0.11</td>
<td>2.8</td>
</tr>
</tbody>
</table>

The ANOVA indicated significant changes of $D$ and IdC with bouts of 25-m. Significant quadratic regression between IdC and $v$ ($0.91<\ R^2<0.99$), power regression between $D$ and $v$ ($0.93<\ R^2<0.98$) and linear regression between IdC and $D$ ($0.64<\ R^2<0.98$) were established for each swimmer; the average equations of each regression were respectively presented in Figures 1, 2 and 3.

DISCUSSION
The main finding of this study was that for national level swimmers, swimming front crawl with arms only, the inter-arm coordination was not linked to $\varepsilon_p$ but related to active drag. Therefore, a high IdC does not automatically guarantee fast speed because the efficiency of the propulsion can be very low. Indeed, Alberty et al. (2009) suggested that a high IdC at the end of a race could be the consequence of fatigued swimmers having the propulsive phases of the hands overlap because the fatigue prohibited enough force generation by a single limb to overcome total drag. Hence, the change in IdC seemed an effective change in coordination to deal with fatigue in the limbs that was related to the balance propulsive and resistive forces.

Fit may be observed from Figures 1 and 3 that, the average speed and the average active drag at which the sample of the 13 swimmers switched from catch-up (IdC<0%) to superposition (IdC>0%) coordination mode were respectively -1.5 m·s$^{-1}$ and -105 N.
On the other hand, the results showed that the whole sample of the 13 swimmers increased their IdC and active drag when speed increased. The inter-arm coordination switched from catch-up to superposition mode at a lower speed value than observed by Seifert et al. (2007b) because in the study, the swimmers swam arms only. The positive linear regression between IdC and active drag confirmed that the environmental constraints (aquatic resistances) led the swimmers to modify their arm coordination in order to overcome these aquatic resistances and to swim faster.

CONCLUSION
In national front crawl swimmers, inter-arm coordination was not linked to $\eta_p$ in the conditions of the experiment. However, even if inter-individual differences of IdC existed at maximal speed, the whole sample of the 13 swimmers changed their inter-arm coordination the same way to adapt to the environmental constraints; notably, a significant positive relationship was found between IdC and active drag. Consequently, if a great IdC does not guarantee $\eta_p$ and high speed, high IdC, together with high power out-put and $\eta_p$, was required to reach high swimming speed and thus overcome the associated active drag. These results suggest that power out-put and $\eta_p$ have to be taken in consideration to interpret arm coordination’s appropriateness for training purposes.

REFERENCES

Modelling Arm Coordination in Front Crawl
Seifert, L., Chollet, D.

CETAPS EA 3832, Faculty of Sport Sciences, University of Rouen, France

Arm coordination changes consistently from catch-up to superposition mode when speed is increased. We modelled the relationships between the index of coordination (IdC) and speed ($V$). The subjects performed an incremental speed test of $8 \times 25$-m steps. After checking the change of arm coordination with speed, five models of regression were tested: power, logarithmic, exponential, linear and quadratic. The model was made by averaging the individual coefficients; then the percent of error with the model was determined for each swimmer. The quadratic modelling ($\text{IdC} = aV^2 + bV + c$) showed the highest coefficient of determination ($0.81 < R^2 < 0.99$) and the lower inter-individual mean error with the model ($21\%$). Arm coordination modelling enables to relate motor control with the performance ($V$), and stroke rate, stroke length and stroke efficiency.

Key words: Biomechanics, motor control, modelling, testing

INTRODUCTION
The aim of modelling is to establish a model containing the whole population in order to understand behavioural changes and to predict performance (Barbosa et al., in press). These authors presented different models such as regression analysis, cluster analysis and the neural network to explain how energetics and biomechanics relate to swimming performance. Hay (2002) showed that in human locomotion (swimming, walking, cycling, kayaking, etc) the relationships between cycle length and speed, and cycle rate and speed correspond to a quadratic model.

Concerning coordination, Chollet et al. (2000) first observed that arm coordination (measured by the index of coordination, IdC) changed from catch-up to superposition mode when the swimmers increased their speed from the 800-m race pace to the 100-m race pace. Imposing eight race paces (from 1500-m to maximal speed), Seifert et al. (2007) modelled the relationships between arm coordination and race paces by two linear regression: flat slope of IdC curve with speed showing a slow increase of arm coordination for long- and mid-distance race paces (from 1500-m to 400-m), then a steep slope of the IdC curve with speed corresponding to a large increase of arm coordination for sprint race paces (from 100-m to maximal speed), the 200-m race pace being the critical race pace separating two kinds of effort. Finally, Seifert and Chollet (2009) have modelled the relationships between the stroking (stroke rate [SR] and stroke length [SL]) and coordinative (IdC) parameters with speed in the four strokes. Using four speeds (and three cycles per speed), these authors established a quadratic regression between SR and V, SL and V, IdC and V for elite male swimmers. The aim of this study was to model the relationships between the index of coordination (IdC) and speed ($V$) for swimmers of various skill levels and specialty.

METHODS
Twenty male swimmers (mean age: 21.8±4.1yr, mean height: 183.8±6.1cm, mean weight: 76.8±9.5kg) of various skill level (7 regional, 10 national and 3 international) and specialty (12 sprinters and 8 distance swimmers) performed an incremental speed test of $8 \times 25$-m steps swimming front crawl arms only (with a pull-buoy to keep the hips at the water surface). Four minutes of rest was allowed between each step.

Two underwater video cameras filmed front and side views at 50Hz. They were connected to a double-entry audio-visual mixer, a video timer, a video recorder and a monitoring screen to mix and genlock the frontal and lateral views on the same screen, from which the mean stroke rate was calculated. A third camera, mixed with the side view for time synchronisation, filmed all trials with a profile view from above the pool. This camera measured the time over the 12.5-m distance (from 10-m
to 22.5 m) to obtain the velocity. Stroke length was calculated from the mean speed and stroke rate values. From the video device, three operators analysed the key points of each arm phase with a blind technique, i.e. without knowing the analyses of the other two operators. Each arm stroke was broken into four phases: entry and catch of the hand in the water, pull, push and recovery. The duration of the propulsive phases was the sum of pull and push phases and that of the non-propulsive phases was the sum of the entry and recovery phases. Arm coordination was quantified using the index of coordination (IdC) defined by Chollet et al. (2000). The IdC represents the lag time between the propulsive phases of each arm. The mean IdC, which was calculated from three complete strokes, was expressed as a percentage of the mean stroke duration. When there was a lag time between the propulsive phases of each arm, the stroke coordination was in “catch-up” (IdC<0%). An IdC>0% indicated that the arms were in “opposition” and IdC>0% corresponded to the “superposition” of the propulsive phases of both arms.

After checking the change of arm coordination with speed by one-way ANOVA with repeated measures, five models of regression were tested: power, logarithmic, exponential, linear and quadratic. Knowing that -30%<IdC<20%, IdC values were normalized between 0 and 1. The model was created by averaging the individual coefficients; then the percent of error ([experimental value-theoretical value]/experimental value x 100) with the model was determined for each swimmer.

RESULTS

Quadratic modelling showed the highest coefficient of determination (R²) and the lower inter-individual mean error with the model among the five models of regression (Table 1).

Table 1. Model of regression between index of coordination (IdC) and speed (V)

<table>
<thead>
<tr>
<th>Regression</th>
<th>Equation</th>
<th>Error</th>
<th>Min R²</th>
<th>Max R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>IdC=0.20V²-69V+10.2</td>
<td>22%</td>
<td>0.64 &lt; R² &lt; 0.97</td>
<td></td>
</tr>
<tr>
<td>Exponential</td>
<td>IdC=0.1x4.94²</td>
<td>155%</td>
<td>0.69 &lt; R² &lt; 0.99</td>
<td></td>
</tr>
<tr>
<td>Logarithmic</td>
<td>IdC=0.62xln(V)+0.19</td>
<td>23%</td>
<td>0.59 &lt; R² &lt; 0.96</td>
<td></td>
</tr>
<tr>
<td>Linear</td>
<td>IdC=0.51V-0.28</td>
<td>26%</td>
<td>0.64 &lt; R² &lt; 0.98</td>
<td></td>
</tr>
<tr>
<td>Quadratic</td>
<td>IdC=0.68V³-1.15V²+0.67</td>
<td>21%</td>
<td>0.81 &lt; R² &lt; 0.99</td>
<td></td>
</tr>
</tbody>
</table>

Relative values of IdC (i.e. IdC values normalised between 0 and 1) were calculated to enable exponential and power modelling, but to have the real coefficient of the quadratic model; the absolute values of IdC were used. Thus the equation for the mean group was: IdC=0.20V²-69V+10.2. The critical value of V for which IdC switched from catch-up to superposition mode closed to -1.5 m·s⁻¹ (Fig. 1).

DISCUSSION

The quadratic regression seemed to be the most appropriate to model the relationships between index of coordination in front crawl (swimming with arms only) and speed for various skill levels and specialty. This result was in accordance with those of Seifert and Chollet (2009) conducted in elite swimmers in whole stroke. Given that drag increased with speed squared, the relationships between IdC and speed should be quadratic and not linear, because if the changes were linear, this would reflect a miss-adaptation of motor control.

The critical value of speed for which IdC switched from catch-up to superposition mode was consistently lower than observed in previous studies (1.5 m·s⁻¹ vs. 1.8 m·s⁻¹), due to the fact that swimmers used arms only. This speed corresponded to the amount for which the wave drag becomes even greater (wave drag amounts to up to 50% of total drag) (Toussaint & Truijens, 2005), explaining that swimmers change their mode of arm coordination to overcome high active drag.

The 21% of inter-individual mean error with the model came from the differences of profile (skill level and specialty), knowing that other factors (such as gender, morphology and anthropometric parameters, training and coaching monitoring) may also explain inter-individual variations. For example, Figure 1 identifies four profiles of swimmers: 1) a small scale of speed and coordination; 2) a small scale of speed and a large scale of coordination; 3) a large scale of speed and a small scale of coordination; 4) a large scale of speed and coordination. The first profile corresponds to swimmers with poor motor flexibility in coordination and speed, (some specialized in only one event and trained mostly in one way. The second profile corresponds to an ineffective large value for coordination, because high speeds cannot be reached. It could be the case of some unskilled swimmers who switched to superposition mode because their hand spent more time in the propulsive phase, due to slow hand speed, but therefore did not generate high force. The third profile corresponds to swimmers with less change in their coordination while still reaching a high speed. This could correspond to swimmers who were focused on the adaptation of the ratio between stroke rate and stroke length rather than on arm coordination. Finally, for the fourth profile, the longer the coordination curve, the greater the swimmer's scale of coordination indicating motor flexibility in coordination. Indeed, the higher the maximal coordination, and the lower the minimal coordination of the curve, the more the swimmer is exploring human limits. In other words, these swimmers attain a range of speeds depending on the type of coordination mode: the catch-up mode by using glide time, or the superposition mode by overlapping the propulsive phases.

CONCLUSION

The current modeling of arm coordination with speed in front crawl allowed analysis of the swimmer's motor control as regards to swimming speed. However, this modeling is mostly useful to understand motor control and not performance directly, because the protocol imposed several steps of 25-m with a complete rest and did not represent competition. Thus, the value of IdC by itself does not indicate the motor skill of the swimmer, but should be used as an indicator of performance or efficiency, such as the stroking parameters (stroke rate and stroke length), the stroke index (speed x stroke length), the intra-cyclic speed variations and the propulsive efficiency.

REFERENCES

Different Frequential Acceleration Spectrums in Front Crawl

Madera, J., González, L.M., García Massó, X., Benavent, J., Colado, J.C., Tella, V.

Universidad de Valencia, Valencia, España

This study analyzed the three different frequency spectrums of acceleration that define the hip acceleration produced by front crawl swimmers during a high-speed test. The swimmers (n=79) performed 25 meters at maximum speed. The acceleration (m/s\(^2\)) was obtained by the derivative analysis of the variation of the swimmer’s hip position with time. The amplitude in the time domain was calculated with the root mean square; while the peak power, the peak power frequency and the spectrum area were calculated in the frequency domain with Fourier analysis. Results showed that 27.85% of the swimmers have a front crawl frequential spectrum of type 1, 30.38% of type 2 and 41.77% of type 3. Type 1 frequential spectrum showed more concentration as opposed to producing accelerations in front crawl and may be the cause of a better efficiency.

Key words: Front crawl swimming, acceleration, spectrum types.

INTRODUCTION

From the biomechanical point of view, swimming performance depends on the mechanical interaction between water and the dynamical actions of the swimmer’s body. From this interaction arises a force opposition (i.e. propulsion vs drag) that is the source of the swimming velocity. All this originates a succession of velocity fluctuations during every swimming cycle (Miller, 1975). These intra-cycle velocity variations have been studied to improve the swimming performance, considering spatial-temporal parameters (Alves et al., 1994; Holmer, 1979; Miyashita, 1971; Vilas-Boas, 1992 and 1996; Alberty et al., 2005; Tella et al. 2006).

Most of the available literature is mainly concentrated on velocity analysis. However, the acceleration is the direct result of the force application that is inferred in swimming. So, there will be major or minor displacements of the swimmer depending on the forces magnitude (Reiwald & Bixler, 2001), being the most effective the forces that produce accelerations in the swimming direction (Bixler, 2005).

With the aim of characterizing the forces applied in the front crawl stroke, Tella et al. (2008) analyzed the acceleration produced in the swimming direction, focusing their analysis on both the time and frequency domains (i.e., the power spectrum analysis) of the swimmers’ hip acceleration. According to these results, the extent of the acceleration generated at specific frequencies may directly influence swimming efficiency. Also, this study presented three spectrum profiles in the frequency domain for front crawl swimming; one, two or more power peak (PP) spectrums.

The main objective of this work was to identify the proportion of the aforementioned type of spectrums in a larger number of front crawl swimmers, and to analyze the differences of both temporal and frequency parameters. As a secondary objective, we related these parameters with performance.

METHODS

After having signed an informed consent, all the procedures described in this study fulfilled the requirements listed in the Helsinki Declaration of 1975 and its later amendment in October 2000, seventy-nine regional and national front crawl swimmers (mean ± standard error of the mean (SEM) age 16.89±0.367 years; weight 63.172±1.3373; height 172.54±1.142 cm) took part in the experiments. The swimmers neither suffered musculoskeletal pathologies nor restrictions, which may have hindered their performance during events.
After a standard warm up (25-30 min), swimmers performed a 25 m front crawl at maximum speed with water start. A reproducibility test was performed for this protocol by taking two individual measurements with a 48-h interval between them.

Swimming acceleration was obtained from the position–time data recorded using a position transducer (SignalFrame, SportMetrics, Valencia, Spain), recording at 1 kHz. The position signal of the velocity was derived twice to obtain the corresponding acceleration signal (m·s⁻²). The apparatus consisted in a resistive sensor (i.e. which produced a resistance of 250 g) with a coiled cable that was fastened to the swimmers’ waists at the height of second and third lumbar vertebrae by means of a belt. All the pre- and post-test data were registered and converted from analogical to digital (12-bit; DAQCard–700; National Instrument, Austin, USA). The data were stored on a hard disk for subsequent analyses. Synchronized to the position signal, several full stroke cycles were recorded using an underwater video camera, perpendicular to the swimmer’s plane of displacement (the signal was registered at 50 Hz).

To analyze the acceleration signals, a specific program was written and run in Matlab 7.1 (R14) (Mathworks Inc., Natick, USA). The acceleration signal was filtered to preserve only those frequencies of interest for the study. A Butterworth fourth-order digital filter was used for this purpose with a band-pass of 1–20 Hz. This signal was then analyzed in both the time and frequency domains. Given the fact that the size of the acceleration is unstable in the first and final seconds for each swimming set, the eight central seconds were selected in each trial to analyze the acceleration signal (Caty et al., 2007). The signal amplitude was examined in the time domain with a root mean square (RMS), and processed in 100 ms-sized blocks. In the case of a set ofמנהoria, the eight central seconds were selected in each trial to analyze the acceleration signal (Caty et al., 2007). The signal amplitude was examined in the time domain with a root mean square (RMS), and processed in 100 ms-sized blocks. In the case of a set of

\[
x_{\text{rms}} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} x_i^2}
\]

The frequency spectrum amplitude was analyzed with the periodogram method (Pollock, 1999), which permits to discover the hidden frequencies in a signal. The periodogram considers all the frequencies and correlates each frequency with the data of the series in order to estimate the importance of a particular frequency in the series. It assigns to each frequency a value called intensity of frequency denoted by:

\[
I(w)=|a(w)|^2 + |b(w)|^2
\]

where \(a(w)=(2/N)\sum_{t=1}^{N} \cos(2\pi w t)\) and \(b(w)=(2/N)\sum_{t=1}^{N} \sin(2\pi w t)\)

The expressions \(a(w)\) and \(b(w)\) can be seen as the covariance of the series with the cosine and sine functions (\(N\), window length; \(t\), time; \(w\), frequency). Note that when \(N\) tends to infinity, the expected value of the “periodogram” equals the true power spectral density of the signal. This was performed by using the Matlab SPECTRUM function, and averaged with the Welch method. A 1024-point Hamming window was used for this purpose. The dependent variables calculated in the frequency domain were: the peak power (PP), the highest value of the power spectrum), the peak power frequency (PPF; the frequency associated with the peak power) and the total power contained in the spectrum area (SA), which is the total power of the whole spectrum between 0 and 20 Hz. Fig. 1 shows an example of the performed analysis.

The images captured on video were used to obtain data for the swimming set. Eight seconds after the third stroke were selected and one cycle was analyzed. This event was used to calculate the average speed corresponding to a swimming series. The mean velocity (V), the stroke frequency (SF) and the stroke length (SL) were obtained with the data of the position in time of the selected swimming set.

The statistical analysis was performed with the SPSS software, version 13.0 (SPSS Inc., Chicago III, USA). The assumed normality (K–S normality test) was verified for all the variables prior to the analyses. To obtain the descriptive statistics (mean, SEM), standard statistical methods were used. One-way ANOVA was performed. ANOVA was performed through Bonferroni post-hoc tests, because of its control over the Type I error (error rate) and its strength when the number of comparisons is small. All differences with \(p<0.05\) were accepted as statistically significant and those with \(p<0.01\) as very significant.

**RESULTS**

Intra-class correlation coefficients of the tests revealed good test re-test reliability (range 0.83–0.89). Subjects were grouped depending on the number of peaks from their frequential spectrum. Figure 1 illustrates the three different types of spectrum that have been obtained in this study. Thus, subjects with only one power peak (PP) in their spectrum have been grouped in type 1. Swimmers with two power peaks (PP) in their spectrum have been grouped in type 2. Subjects with three or more power peaks (PP) have been grouped in type 3 (Table 1).

Figure 1. Three swimmers’ spectrums are represented. Swimmer ‘a’ concentrates all his acceleration in only one PP, swimmer ‘b’ in two and swimmer ‘c’ in three or more.

Table 1: number and percentage of swimmers whose swimming belongs to each type of frequential spectrum.

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>n</th>
<th>Spectrum %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>22</td>
<td>27.85%</td>
</tr>
<tr>
<td>Type 2</td>
<td>24</td>
<td>30.38%</td>
</tr>
<tr>
<td>Type 3</td>
<td>33</td>
<td>41.77%</td>
</tr>
<tr>
<td>Total</td>
<td>79</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2 shows descriptive data in the time domain for each one of the different frequential spectrums and the significantly statistic differences among them. Post-hoc study shows differences among the RMS values in groups 1 and 2 (\(p<0.01\)). Velocity (V) shows differences between groups 1 and 2 (\(p<0.05\)).

Table 3 shows frequential descriptive of the different spectrums and the statistically significant differences among them. Post-hoc analysis showed that the PP differences among groups were between 1 and 2 (\(p<0.01\)) and 1 and 3 (\(p<0.05\)) spectrum type, while SA differences were between 1 and 2 (\(p<0.01\)) groups.
Due to the spectrum concentration or dispersion, we have grouped them. Acceleration production is on different frequencies, then the frequency acceleration production during front crawl swimming. When the acceleration spectrum types are related to the concentration or dispersion in the spectrums show a dispersion of the accelerations. So, the analyzed concentration of the accelerations. However, if more peaks are observed, the acceleration shows only one peak, then this spectrum highlights the concentration of the accelerations to only one frequency. By concentrating the accelerations on the same frequency may be subject to efficiency and propulsive coordination aspects. Future studies should be done to analyze the frequent spectrums produced by different coordination or efficiency situations.

Intracyclic accelerations during a front crawl stroke are the cause of, mainly, the actions of arms, legs, and body when interacting with the water flow. Counsilman & Wasilak (1982) showed six accelerations for each swimming cycle. The analyzed sample in this work shows an average PPF of 5.55 Hz. If the measure unit of the frequency is expressed in Hz and we normalize this frequency depending on the time length of one cycle (PPF (cycle) = PPF (Hz) / [SF · 60]), then the acceleration frequency in one cycle would be 6.27. This indicates that the swimmers’ main concentration of accelerations in all the spectrums is produced at six for each stroke cycle, possibly as the result of the propulsive actions of arms and legs. Due to our study limitations, all the produced accelerations in other frequencies are hard to explain, and these accelerations, according to our results, may represent low efficiency in the front crawl swimming performance.

The RMS of the acceleration represents its effective value. A previous study (Tella et al., 2008) showed its positive and strong correlation with swimming speed (i.e. the higher RMS, the higher speed). About the temporal analysis, our RMS values were similar to those obtained by Tella et al. (2008). The RMS differences that have been found between types 1 and 2 spectrums confirm that the spectrums with all the accelerations concentrated in only one frequency result in more effective acceleration values. Also, type 1 swimmers obtained superior values than type 2 and 3, although differences were only significant between 1 and 3. Maybe the lack of significant differences between 1 and 2, and 2 and 3 types is caused by a statistical type II error. If this is the cause, a larger subject sample might indicate that more than 3 peaks spectrums would be more efficient than the 2 peaks spectrums.

In the frequent analysis, the PPF values are similar to those obtained in other studies. In the work by Tella et al. (2008), the PPF value was 5.88±0.31, and in our work the average value was 5.55±0.12. In both studies, once the acceleration frequency has been normalized to a swimming cycle, frequency is next to 6 (Counsilman & Wasilak, 1982).

To conclude, the type 1 frequent spectrums show more application and its higher RMS can discriminate to the more efficient swimmers.

REFERENCES

### Table 2. Temporal values.

<table>
<thead>
<tr>
<th>Spectrum Type</th>
<th>N</th>
<th>Mean (m·s(^{-2}))</th>
<th>SEM</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA (m·s(^{-2}))</td>
<td>1</td>
<td>53.24</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>53.21</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>53.21</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>79</td>
<td>53.22</td>
<td>0.50</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. Frequency values.

<table>
<thead>
<tr>
<th>Spectrum Type</th>
<th>N</th>
<th>Mean (m·s(^{-2}))</th>
<th>SEM</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V (m·s(^{-1}))</td>
<td>1</td>
<td>2.2</td>
<td>1.61</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.4</td>
<td>1.69</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.3</td>
<td>1.76</td>
<td>0.04</td>
</tr>
<tr>
<td>Total</td>
<td>79</td>
<td>1.75</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

### DISCUSSION

The observation of the spectrum patterns has allowed us to group the swimmers into three different types. These patterns are similar to those described by Tella et al. (2008). If the frequency spectrum of the acceleration shows only one peak, then this spectrum highlights the concentration of the accelerations. However, if more peaks are observed, the spectrums show a dispersion of the accelerations. So, the analyzed spectrum types are related to the concentration or dispersion in the acceleration production during front crawl swimming. When the accelerations production is on different frequencies, then the frequency spectrum will show as many peaks as the number of found frequencies. Due to the spectrum concentration or dispersion, we have grouped them depending on the number of observed peaks. Thus, swimmers whose frequency spectrum corresponds to type 1 show their concentration in all their accelerations into an average PPF of 5.54 Hz. While swimmers with more than one PP (types 2 and 3) show more dispersion as they accelerate into different frequencies. The results show that swimmers who concentrate their accelerations in only on peak (type 1) obtain superior PP values (approximately 50%). This concentration might be the cause of these values. Also, the higher concentration of accelerations agrees with superior values in V, RMS and SA, although there are only significant differences with type 2. This might reveal the importance of concentrating the accelerations to only one frequency. By concentrating the accelerations on the same frequency may be subject to efficiency and propulsive coordination aspects. Future studies should be done to analyze the frequent spectrums produced by different coordination or efficiency situations.


**The Gliding Phase in Swimming: The Effect of Water Depth**


1. University of Beira Interior, Covilhã, Portugal
2. Research Centre in Sports, Health and Human Development, Vila Real, Portugal
3. Polytechnic Institute of Bragança, Bragança, Portugal
4. IIT Kharagpur, Mumbai, India
5. University of Porto, Faculty of Sport, Porto, Portugal
6. Research Centre of Education, Innovation and Intervention in Sports, Porto, Portugal
7. University of Savioe, Chambery, France
8. University of Trás-os-Montes and Alto Douro, Vila Real, Portugal

The aim of this study was to analyse the effect of depth on drag during the underwater gliding. CFD simulations were applied to the flow around a 3D model of a male adult swimmer in a prone gliding position with the arms extended at the front. The domain to perform the simulations was created with 3.0 m depth, 3.0 m width and 11.0 m length.

The drag coefficient and the hydrodynamic drag force were computed, using a steady flow velocity of 2.50 m/s for depths of 0.20, 0.50, 1.0, 1.50, 2.0, 2.50 and 2.80 m. As the depth increased, the drag coefficient and drag force decreased. The water depth seems to have a positive effect on reducing hydrodynamic drag during the gliding after starts and turns, although a compromise between decreasing drag (by increasing water depth) and gliding travel distance should be a main concern of swimmers.

**Key words:** CFD, Hydrodynamics, Simulations, Human model

**INTRODUCTION**

Aiming to achieve higher performances, swimmers should take full advantage of each component of swimming race to stand out in swimming competitions. During starts and turns, the gliding phase represents a determinant race component. During the crucial gliding phase, swimmers must minimize the hydrodynamic drag force resisting forward motion. The position adopted by the swimmers under the water represents an important concern and seems to determine the success of the start (Vilas-Boas et al., 2000). Another interesting and less studied issue is related to the ideal depth to perform this underwater gliding. Vennel et al. (2006) showed that to avoid significant wave drag, a swimmer must be deeper than 1.8 chest depths and 2.8 chest depths below the surface for gliding velocities of 0.90 m/s and 2.0 m/s, respectively, which corresponds to water depths of 0.45 m and 0.70 m, respectively, for a swimmer with 0.25 m of chest depth. Lyttle et al. (1999) also showed that there is no significant wave drag when a typical adult swimmer is at least 0.60 m under the water surface. In both studies, at water depths higher than these values, hydrodynamic drag was almost constant, depending only on viscous and form drag. However, one can notice that new swimming pools attempted to incorporate some key elements that characterize a “fast swimming pool”, as the Beijing 2008 swimming pool (The Beijing Bubble Building, “The Ice Cube”), with its 3.0 m depth, is a good example. Additionally, one can also observe some elite swimmers performing this underwater gliding at higher depths. Thus, using computational fluid dynamics methodology one can compute the hydrodynamic drag when gliding at different water depths (Bixler et al., 2007).

Hence, the aim of this study was to analyse the effect of depth on drag during the underwater gliding in a swimming pool of 3.0 m depth, using computational fluid dynamics.
METHODS
To obtain the geometry of a male human body, a model was created through computer tomography scans techniques (Marinho et al., 2010). The surfaces of the swimmer were then developed using ANSYS-FLUENT 6.3 pre-processor GAMBIT (Ansys Inc., Canonsburg, USA). The entire computational domain was volume meshed and solved through FLUENT solver.

The three-dimensional computational domain representing a part of swimming pool was about 3.0 m in depth, 3.0 m wide and 11.0 m in length. The entire computational domain consisted of 900 millions cells of hybrid mesh composed of prisms and pyramids.

Computational fluid dynamics simulations were carried out to simulate the flow around a three-dimensional model of a male adult swimmer in a prone gliding position with the arms extended at the front (Marinho et al., 2009). General Moving Object (GMO) model was used to model the body as the moving object. During the gliding, the swimmer model’s horizontal axis line running lengthwise was placed at different water depths viz., (i) 0.20 m (just under the surface), (ii) 0.50 m, (iii) 1.0 m, (iv) 1.50 m (middle of the pool), (v) 2.0 m, (vi) 2.50 m and, (vii) 2.80 m (bottom of the pool), respectively. The drag coefficient and the hydrodynamic drag force were computed using a steady flow velocity of 2.5 m/s for the different depths in each case.

RESULTS
Table 1 presents the drag coefficient and the drag force values when gliding at a water depth of 0.20 m, 0.50 m, 1.0 m, 1.50 m, 2.0 m, 2.50 m and 2.80 m. These values were computed at the time of 2 seconds when the swimmer was approximately at the middle of the computational pool.

It was observed that, both drag coefficient and drag force values fall with increase in depth of swimming tank, which swimmer model is chosen for simulation of gliding.

<table>
<thead>
<tr>
<th>Water depths (m)</th>
<th>Drag coefficient</th>
<th>Drag force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>0.67</td>
<td>100.20</td>
</tr>
<tr>
<td>0.50</td>
<td>0.62</td>
<td>92.30</td>
</tr>
<tr>
<td>1.00</td>
<td>0.53</td>
<td>80.50</td>
</tr>
<tr>
<td>1.50</td>
<td>0.44</td>
<td>65.40</td>
</tr>
<tr>
<td>2.00</td>
<td>0.36</td>
<td>53.40</td>
</tr>
<tr>
<td>2.50</td>
<td>0.30</td>
<td>44.70</td>
</tr>
<tr>
<td>2.80</td>
<td>0.28</td>
<td>42.00</td>
</tr>
</tbody>
</table>

DISCUSSION
The aim of this study was to analyse the effect of depth on drag during the underwater gliding, using computational fluid dynamics. It was noticed that hydrodynamic drag decreased with depth increase, presenting the lowest hydrodynamic drag values near the bottom of the computational swimming pool (water depth of 2.80 m).

Computational fluid dynamics methodology has been shown to be a reliable tool to examine the water flow around a submerged human body model (Bixler et al., 2007). Thus, an attempt was performed to analyse the hydrodynamic drag during the underwater gliding, simulating a swimming pool with 3.0 m depth and to verify if drag values remained constant at depths higher than a critical point, beyond which wave drag seems to be almost null (Lyttle et al., 1999; Vennel et al., 2006).

The water depth seems to have a positive effect on reducing hydrodynamic drag during the gliding. Moreover, gliding near the bottom of the pool also presented lower drag values compared to gliding at a water depth, for instance, in the middle of the swimming pool. This finding could suggest that the positive effects of water depth are more powerful than the possible negative hydrodynamic effects of turbulence near the bottom of the pool, expected when the simulations are not carried-out with a moving model. In fact, one of the innovations of this study was the possibility to carry-out the simulations and the drag analysis with a moving human body, as performed by Lecrivain et al. (2008) in the analysis of the upper arm propulsion.

The values found in this study, concerning hydrodynamic drag, were very similar to others presented in CFD studies (e.g., Bixler et al., 2007; Marinho et al., 2009), using similar velocities and similar water depths. Nevertheless, in opposition to what occurred in the studies of Lyttle et al. (1999) and Vennel et al. (2006), hydrodynamic drag decreased with depth, in the entire range of depths computed in FLUENT 6.3 (0.20 m to 2.80 m). These differences signify an interesting aspect for future investigation and to further analysis with computational fluid dynamics simulations. However, one can attribute these differences between the experimental analysis and computational fluid dynamics could be one of the reasons not to find good match of data. Indeed, although significant improvements on computational fluid dynamics simulations, it raises the question, whereas this methodology truly represents the real swimming conditions. In this paper, a significant effort was performed to diminish this difference, using a moving human body. We believe this approach could lead to obtain more accurate results. In the future, it should be also attempted to perform the same analysis with the swimmer kicking (underwater dolphin kicking), since the time when the swimmer is passively gliding is very short comparing with the total underwater distance. Moreover, active drag can be significantly different from passive drag values (Kjendlie & Stallman, 2008), thus generalizing these data to the underwater dolphin kicking should be made with careful.

CONCLUSIONS
Reducing the drag experienced by swimmers during the glide of the wall can enhance start and turn performances. Therefore, a compromise between decreasing drag (by increasing swimmer’s depth from water surface) and gliding travel distance should be a main concern of swimmers and an important goal to be studied in future investigations. Although increasing depth position could contribute to decrease drag force, this reduction seems to be lower with depth, especially after 2.0 m depth, thus suggesting that possibly performing the underwater gliding (and the underwater dolphin kicking) more than 2.0 m depth could not be gainful for the swimmer.

REFERENCES


**ACKNOWLEDGEMENTS**

This work was supported by the Portuguese Government by Grants of FCT (PTDC/DES/098532/2008).

---

**A Method to Estimate Active Drag over a Range of Swimming Velocities which may be used to Evaluate the Stroke Mechanics of the Swimmer**

Mason, B.R. 1, Formosa, D.P. 1, Toussaint, H.M. 2

1 *Australian Institute of Sport, Australia*
2 *Innoport, The Netherlands*

This research project aimed to estimate values of active drag over a range of swimming velocities. The data required to do this was the passive drag values for the swimmer at various swim velocities, together with the active drag force value for the individual at their maximum swim velocity. The drag force is represented by an exponential equation \( F = a \cdot e^{bV} \), where \( a \) and \( b \) are constants for a particular swimmer. The constant \( a \) (passive) reflects the more innate characteristics of the individual swimmer and their suitability to aquatics motion. The constant \( a_p \) (active-passive) reflects the efficiency of the swimmer's technique. In both cases, the lower the constant's value, the better suited the swimmer is to aquatics motion or to technical efficiency. The \( a_p \) and the \( a \) provide an index to evaluate a swimmer's capabilities.

**Keywords:** Biomechanics, swimming, active drag, passive drag, stroke mechanics

**INTRODUCTION**

A swimmer’s ability to swim faster is depended upon an increase of propulsive force, which exceeds the drag force presently acting on the swimmer’s motion. However, active drag increases exponentially with a progressive increase in the swimmer’s mean velocity. When the active drag and mean maximal propulsive force generated by the swimmer reach equilibrium, the swimmer attains their mean maximum swim velocity. However, at any constant swim velocity, mean active drag is equal in magnitude to the mean propulsive force exerted by the swimmer. Knowing the magnitude of the mean active drag opposing the forward motion provides information that may be used to evaluate the swimmer's mean propulsive force.

Initially it was thought that tethered swimming would provide a reasonable measure of the swimmer's propulsion. Researchers have discounted this theory (Mason et al, 2009a). The MAD system developed in the Netherlands provided a measure of active drag at different velocities (Toussaint et al, 2004). However, researchers have questioned whether the swimming actions using the MAD system represent swimming propulsive technique. The major challenge researchers faced was the ability to measure total propulsive force generated by the swimmer during the free swim phase. Therefore, methods were developed to estimate the swimmers’ mean propulsive force. The Velocity Perturbation Method provided a value for active drag, however only at the swimmer’s maximum velocity (Kolmogorov & Duplishcheva, 1992). Similarly, a method developed at the Australian Institute of Sport also identified the magnitude of active drag at maximum swim velocity (Formosa et al., 2009). Both these methods used to evaluate active drag were dependent upon the assumption that the swimmer applied equal power while swimming at their maximum velocity during the free swim and assisted/resisted conditions. Passive drag is measured at various velocities by towing the swimmer in a streamline position. Researchers have identified that the measurement of passive drag was highly correlated to that of active drag at the swimmer’s maximum velocity (Mason et al, 2009b). This high relationship between active and passive drag justified the procedures used in this present research project.

The aim of this study was to develop a method to estimate the active drag of the swimmer over a full range of swimming velocities. The method developed relied upon having mean passive drag measures of the swimmer over a range of velocities, as well as the mean active drag of the swimmer at the swimmer’s maximum swim velocity.
METHODS
Eleven Australian (2 male; 9 female) national freestyle swimmers participated in the study. Seven were members of the Australian swimming team at the Beijing Olympics.
Each of the subjects completed all the tests required in a single individual testing session. The subjects were given sufficient rest between test trials so that fatigue would not be an issue. Firstly, subjects completed three maximum velocity trials over a 10 m interval, starting from 25 m out and the velocity was measured from 15 m to 5 m out from the wall. The velocity was determined using video cameras with a resolution of 0.02 s. The fastest trial was utilised to determine the subject’s maximum swim velocity.
The equipment used in the active and passive drag testing consisted of a motorised towing device that could tow a swimmer over a range of constant velocities. The towing device was mounted on a Kistler force™ platform which enabled the force required to tow the subject to be monitored. The eight component force signals from the force platform were captured by computer at a 500 Hz sampling rate. Only the Y component was utilized and was smoothed with a 5 Hz low pass digital filter. Four complete stroke cycles were captured for analysis and extra data on either side of these strokes was also collected to allow for smoothing. The velocity of the towing device was also monitored for accuracy with the video camera system.
In the passive drag testing the tow rope was attached to the swimmer by way of a loop through which the subject’s fingers could grasp. Following passive drag familiarization, three passive drag trials were completed at the subject’s constant maximum swim velocity and the mean tow force value from the three trials used. The subject was towed through the water ensuring a shallow laminar flow over the body. A series of passive drag trials was next completed over a range of 10 different tow velocities from 2.2 to 1.0 m s⁻¹. Only a single trial was completed for each velocity.
Finally, in the active drag testing the rope was attached to a belt around the swimmer’s waist. The five active drag trials were completed at a five percent greater velocity than the swimmer’s maximum swim velocity to ensure a force was always applied by the towing device. The swimmers were instructed to swim at maximum effort for each of the trials. The detailed equations used to determine active drag from the recorded towing force that represented active drag at the swimmer’s maximum velocity are described in previous articles by the researchers (Formosa et al, 2009). The mean of the middle three values was used as the value for active drag.

RESULTS
The exponential function used to determine the passive drag equations was as indicated. \( F = a \cdot e^{(b \cdot V)} \) where \( a \) and \( b \) are constants for a particular swimmer.
The first step to create the equation was to plot the curve for passive drag and obtain LN (logarithmic value to the base e) values for passive drag. The processes for subject 7 are displayed and illustrate the procedures used.

\[
\text{Tow Velocity (m·s}^{-1}) \quad \text{Smoothed LN(Pass drag)} \quad \text{Smoothed Pass Drag (N)}
\]

<table>
<thead>
<tr>
<th>Tow Velocity (m·s⁻¹)</th>
<th>Smoothed LN(Pass drag)</th>
<th>Smoothed Pass Drag (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2</td>
<td>4.85</td>
<td>127.28</td>
</tr>
<tr>
<td>2.1</td>
<td>4.69</td>
<td>109.29</td>
</tr>
<tr>
<td>2.0</td>
<td>4.54</td>
<td>93.84</td>
</tr>
<tr>
<td>1.9</td>
<td>4.39</td>
<td>80.58</td>
</tr>
<tr>
<td>1.8</td>
<td>4.25</td>
<td>70.25</td>
</tr>
<tr>
<td>1.8</td>
<td>4.24</td>
<td>69.19</td>
</tr>
<tr>
<td>1.7</td>
<td>4.08</td>
<td>59.41</td>
</tr>
<tr>
<td>1.6</td>
<td>3.93</td>
<td>51.01</td>
</tr>
<tr>
<td>1.5</td>
<td>3.78</td>
<td>43.80</td>
</tr>
<tr>
<td>1.5</td>
<td>3.47</td>
<td>32.29</td>
</tr>
<tr>
<td>1.4</td>
<td>3.17</td>
<td>23.81</td>
</tr>
</tbody>
</table>

The smoothed curve of passive drag against velocity was then able to be plotted and the exponential equation for passive drag determined.
\[ F = a \cdot e^{(b \cdot V)} \]
\[ a = \exp(1.4936) = 4.454 \]
\[ b = 1.524 \]

The next stage in the process was to find a linear trend line for the graph of LN(drag) against time and the equation that represented that trend line. The smoothed passive drag values could then be computed as \( \exp(1.524 \cdot \text{Velocity} + 1) \)
The variable for the active drag equation could then be computed through substitution knowing the one value for active drag at the swimmer’s maximum swim velocity.

\[ \text{where } 210 \text{ N} = \text{active drag at } 1.81 \text{ m}\text{s}^{-1} \]

Table 1: Characteristics of each swimmer, together with the constants used to derive the active and passive drag equations. \( a \) is the constant for active drag, \( a_p \) is the constant for passive drag and \( a_{a-p} \) is the constant for the difference between active and passive drag. \( b \) is a constant representing a swimmer’s overall drag.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Event (m)</th>
<th>R² Trend</th>
<th>( a_p )</th>
<th>( b )</th>
<th>( a_a )</th>
<th>( a_{a-p} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>200</td>
<td>0.9921</td>
<td>8.01</td>
<td>1.21</td>
<td>19.97</td>
<td>11.96</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>200</td>
<td>0.9702</td>
<td>3.91</td>
<td>1.59</td>
<td>18.68</td>
<td>14.78</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>200</td>
<td>0.9944</td>
<td>3.81</td>
<td>1.48</td>
<td>18.92</td>
<td>15.11</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>100</td>
<td>0.9831</td>
<td>5.21</td>
<td>1.29</td>
<td>22.97</td>
<td>17.77</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>100</td>
<td>0.9779</td>
<td>5.60</td>
<td>1.28</td>
<td>22.12</td>
<td>16.52</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>400</td>
<td>0.9718</td>
<td>5.99</td>
<td>1.29</td>
<td>14.63</td>
<td>8.64</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>200</td>
<td>0.9957</td>
<td>4.45</td>
<td>1.52</td>
<td>13.31</td>
<td>8.86</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>200</td>
<td>0.9859</td>
<td>4.84</td>
<td>1.45</td>
<td>11.42</td>
<td>6.59</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>100</td>
<td>0.9768</td>
<td>6.43</td>
<td>1.21</td>
<td>19.85</td>
<td>13.41</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>200</td>
<td>0.9819</td>
<td>4.91</td>
<td>1.36</td>
<td>24.57</td>
<td>19.67</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>200</td>
<td>0.9879</td>
<td>6.07</td>
<td>1.31</td>
<td>15.83</td>
<td>9.76</td>
</tr>
</tbody>
</table>

**DISCUSSION**

In both active and passive drag equations, the value of the drag force is represented as an exponential function of swimming velocity. The active drag values will however rise or increase more rapidly than that of passive drag. There will still be a similar exponential relationship between the two curves and only the increased rate of rise will differentiate between the active and passive drag equations. Given that the rate of rise between the active and passive drag equations is represented by a single constant, these two constants may be used as an index to describe the individual swimmer’s capabilities. The constant in the equation for passive drag would represent an index of the swimmer’s innate physical characteristics such as size, shape and cross sectional frontal surface area. A lower index indicates a more efficient body shape for aquatic movement. The difference between the constant used in the active drag equation and the constant in the passive drag equation could be used as an index to represent the efficiency of the swimmer technique. This index may provide insight as to the capability of the swimmer to compete in particular events.

Exponential functions for both active and passive drag were expressed by the equation \( F = ae^{bV} \), where \( b \) was constant for a particular swimmer and \( a \) defined the active or passive drag constant. The \( a_a \) represented the constant used in the active drag equation, \( a_p \) represented the constant used in the passive drag equation and \( a_{a-p} \) represented the constant used for the difference between active and passive drag. The constant \( a \) was useful, in that \( a_p \) defined the unique aquatic characteristics of the individual. This research suggested that the lower the number, the more effective the individual characteristic was with respect to movement through water. The constant \( a_{a-p} \) provided valuable insight into the efficiency of the swimmer’s technique. Once again, the lower the value of \( a_{a-p} \) the more efficient was the technique. For example, subject six was the Australian 400 m freestyle champion over a number of consecutive years. The data identified that subject six had a lower \( a_{a-p} \) value than all but one other subject. This highlighted that subject six had an efficient technique. Similarly, subject eight presented the lowest \( a_{a-p} \) value and she demonstrated excellent technical skills. Subject one had the highest \( a_p \) value and this indicated his anthropometric characteristics were not ideal for swimming. However, the \( a_{a-p} \) value demonstrated good technical efficiency in the swimmer. The examination of the \( a_{a-p} \) of swimmers at various times in the season may identify changes in technical efficiency.
CONCLUSION
The present study demonstrated the importance of being able to generate an equation to represent a swimmer’s active drag over a range of velocities. This novel concept may provide insight as to the suitability of the individual to swim specific swimming events, as well as indicate the efficiency of the swimmer’s technique. This will provide valuable information to coaches and swimmers regarding the athlete’s suitability to the sport, as well as provide an evaluation of improvement in technical efficiency.

REFERENCES

ACKNOWLEDGMENTS
The researchers would like to thank the Australian Institute of Sport Swimming programme and Australian National Swim team for their participation in the study.

50m Race Components Times Analysis Based on a Regression Analysis Model Applied to Age-Group Swimmers

Morales, E., 1 Arellano, F., Femía, P., 1 Mercade, J., 1, Haljand R. 2

1University of Granada, Spain
2University of Tallinn, Tallinn, Estonia

This investigation aimed to develop a regression model of the Race Component evolution in a large sample of regional age-group Spanish swimmers. Subjects were 280 regional swimmers selected of different clubs. The time spent starting (ST), the time spent stroking (STT1 - STT2), the time spent turning (TT) and the time spent finishing (FT), were used for analysis. Inverse function approximation of the partials times by aging and was carried out. Furthermore, regression analysis of partials times and event time for age and genders were calculated, respectively. It seems that the times of the swimmers studied have a tendency to resemble international swimmer’s times. The estimation formula applied was different time according to gender. The crossing age in the swimming partials times were about 12-14 years old.

Key words: performance development, competition analysis, technique testing

INTRODUCTION
The dynamic process of training needs as much information as possible from competitive performance, which, together with information from training and testing, will help to the coach to monitor the training program.

Race components (RC) data must be considered when analysing swimming performances during international swimming competitions (see www.swim.ee). To improve the swimmer testing efficiency, this analysis has also to include the results of swimming tests made during a training season or several training seasons.

The RC is composed of the starting time (ST), stroking (STT), turning (TT) and finishing (FT) (Pai, Hay, & Wilson, 1984). Swimming training has to be oriented to improve all racing components, but the lack of a specific model makes it difficult to know which are the strongest and weakest race components of any individual. The coach must train the swimmer according to swimming time and age. The 50m freestyle performances should improve with age in each period of growth, in parallel with the RC.

Some studies have been published where regression equations were applied in the analysis of RC obtained from different competitions (Ab-salamov & Timakovoy, 1990; Arellano et al., 1996; Nomura, 2006). The study aim was to develop a regression model of the RC evolution in a large sample of regional age-group Spanish swimmers.

METHODS
The sample was composed of 180 regional swimmers (162 males and 118 females). The age of these subjects ranged from 9 to 22 years.

The procedures that have been used to record the times obtained by swimmers during the performance test of 50 m freestyle were: a) references were put on the swimming pool at the distances selected (5, 10, 15 and 20 m) to know when the head crossed this line; b) the 50m trials were recorded by five video cameras connected to a mini DV video recorder through a video-timer and video selector; c) the images from the first two video cameras were mixed to see the over- and under-water phases of the start in the same frame (until 5m); d) third and fourth cameras were used to measure the 10 and 15 m time; the fifth camera was placed at the end of the swimming pool for video recording the turning phase (20 and 25 m) and; e) all the images from the cameras
were recorded at a distance of 8 m from the perpendicular plane of the swimmer’s displacement (see figure 1).

Figure 1. Picture with the references and video cameras set-up on the swimming pool.

The regression analysis was developed using the SPSS 17.0 statistical software (SPSS Inc., Chicago, Ill., USA). Kolmogorov-Smirnov test showed the normal distribution of the sample. The regression analysis was used to discover the tendency and model of the RC. Inverse function approximation of the RC times (ST, STT, TT, FT) by age (AGE) and gender (GEN) was carried out. The type of generic equation obtained was:

\[
y = a + a' \cdot \text{GEN} + b \cdot \frac{1 - b' \cdot \text{GEN}}{\text{AGE}}
\]

(1)

The estimation formula of time from age and gender was as follows:

\[
\begin{align*}
\text{ST}_{\text{Max}} &= a_t + \frac{b}{\text{AGE}} \\
\text{ST}_{\text{Min}} &= a_t + \frac{b_t}{\text{AGE}}
\end{align*}
\]

(2)

Furthermore, the regression analysis and inverse function for every partial time was calculated respectively.

RESULTS

Each RC time with related to the final time and expressed as a percentage. Student T-tests for independent samples demonstrated significant differences between genders for each partial time (Table 1).

Table 1. T-test for independent samples according to gender in each percentage of partial times.

<table>
<thead>
<tr>
<th>Var.</th>
<th>Means</th>
<th>Difference</th>
<th>E.T</th>
<th>T (gl)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>%ST</td>
<td>Male.</td>
<td>26.280</td>
<td>-0.29</td>
<td>0.05</td>
<td>-5.05</td>
</tr>
<tr>
<td></td>
<td>Female.</td>
<td>26.840</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%STT1</td>
<td>Male.</td>
<td>10.291</td>
<td>-0.35</td>
<td>0.04</td>
<td>-8.47</td>
</tr>
<tr>
<td></td>
<td>Female.</td>
<td>10.669</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%TT</td>
<td>Male.</td>
<td>30.575</td>
<td>0.33</td>
<td>0.05</td>
<td>5.58</td>
</tr>
<tr>
<td></td>
<td>Female.</td>
<td>30.131</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%STT2</td>
<td>Male.</td>
<td>22.251</td>
<td>-0.07</td>
<td>0.05</td>
<td>-1.36</td>
</tr>
<tr>
<td></td>
<td>Female.</td>
<td>22.330</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%FT</td>
<td>Male.</td>
<td>10.439</td>
<td>0.39</td>
<td>0.03</td>
<td>10.77</td>
</tr>
<tr>
<td></td>
<td>Female.</td>
<td>10.041</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; ***p<0.001 *Welch’s test

The regression analysis was used to discover the tendency and model of evolution of partial times according to age and gender. The type of equations obtained for gender in each partial time and event time can be observed in Table 3.

Table 3. Model of regression analysis of the partial time (ST, STT1, TT, STT2 FT) by age (AGE) and gender (GEN)

<table>
<thead>
<tr>
<th>Male Models</th>
<th>R²</th>
<th>Female models</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST = 1.695+97.673*age⁻¹</td>
<td>*** 0.655</td>
<td>ST = 2.933+84.528*age⁻¹</td>
<td>*** 0.723</td>
</tr>
<tr>
<td>STT1 = 0.514+40.047*age⁻¹</td>
<td>*** 0.570</td>
<td>STT1 = 1.061+33.463*age⁻¹</td>
<td>*** 0.682</td>
</tr>
<tr>
<td>TT = 0.493+131.302*age⁻¹</td>
<td>*** 0.608</td>
<td>TT = 2.433+106.729*age⁻¹</td>
<td>*** 0.628</td>
</tr>
<tr>
<td>STT2 = -0.630+107.716*age⁻¹</td>
<td>*** 0.549</td>
<td>STT2 = 0.998+87.557*age⁻¹</td>
<td>*** 0.635</td>
</tr>
<tr>
<td>FT = -0.606+54.428*age⁻¹</td>
<td>*** 0.617</td>
<td>FT = -0.043+46.999*age⁻¹</td>
<td>*** 0.573</td>
</tr>
<tr>
<td>T50 = 1.443+431.231*age⁻¹</td>
<td>*** 0.647</td>
<td>T50 = 7.323+360.161*age⁻¹</td>
<td>*** 0.703</td>
</tr>
</tbody>
</table>

***P<0.001

The percentages of partial times of the younger swimmers from our study were compared with percentages of partial times of international swimmers in the European Championship (the average of times from 2000 to 2005) (Table 2). The comparison is between percentages related to the final time, but the swimming pools are different length (25m in younger swimmers and 50m in international swimmers). These times were published at website: http://www.swim.ee/competition.

Table 2. Results of T-test for independent samples in accordance with younger swimmers (Younger S.) from our study and international swimmers in European Championships (Elite).

<table>
<thead>
<tr>
<th>Var.</th>
<th>Younger S.</th>
<th>Elite</th>
<th>Means</th>
<th>Difference</th>
<th>E.T</th>
<th>t (gl)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>%ST</td>
<td>26.44</td>
<td>26.840</td>
<td>-0.29</td>
<td>0.05</td>
<td>-5.05</td>
<td>0.001***</td>
<td></td>
</tr>
<tr>
<td>%STT1</td>
<td>10.317</td>
<td>10.669</td>
<td>-0.35</td>
<td>0.04</td>
<td>-8.47</td>
<td>0.001***</td>
<td></td>
</tr>
<tr>
<td>%TT</td>
<td>30.462</td>
<td>30.131</td>
<td>0.33</td>
<td>0.05</td>
<td>5.58</td>
<td>0.001***</td>
<td></td>
</tr>
<tr>
<td>%STT2</td>
<td>22.251</td>
<td>22.330</td>
<td>-0.07</td>
<td>0.05</td>
<td>-1.36</td>
<td>0.172</td>
<td></td>
</tr>
<tr>
<td>%FT</td>
<td>10.439</td>
<td>10.041</td>
<td>0.39</td>
<td>0.03</td>
<td>10.77</td>
<td>0.001***</td>
<td></td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01, ***p<0.001 *Welch’s test

The regression analysis was used to discover the tendency and model of evolution of partial times according to age and gender. The type of equations obtained for gender in each partial time and event time can be observed in Table 3.

Table 3. Model of regression analysis of the partial time (ST, STT1, TT, STT2 FT) by age (AGE) and gender (GEN)

<table>
<thead>
<tr>
<th>Male Models</th>
<th>R²</th>
<th>Female models</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST = 1.695+97.673*age⁻¹</td>
<td>*** 0.655</td>
<td>ST = 2.933+84.528*age⁻¹</td>
<td>*** 0.723</td>
</tr>
<tr>
<td>STT1 = 0.514+40.047*age⁻¹</td>
<td>*** 0.570</td>
<td>STT1 = 1.061+33.463*age⁻¹</td>
<td>*** 0.682</td>
</tr>
<tr>
<td>TT = 0.493+131.302*age⁻¹</td>
<td>*** 0.608</td>
<td>TT = 2.433+106.729*age⁻¹</td>
<td>*** 0.628</td>
</tr>
<tr>
<td>STT2 = -0.630+107.716*age⁻¹</td>
<td>*** 0.549</td>
<td>STT2 = 0.998+87.557*age⁻¹</td>
<td>*** 0.635</td>
</tr>
<tr>
<td>FT = -0.606+54.428*age⁻¹</td>
<td>*** 0.617</td>
<td>FT = -0.043+46.999*age⁻¹</td>
<td>*** 0.573</td>
</tr>
<tr>
<td>T50 = 1.443+431.231*age⁻¹</td>
<td>*** 0.647</td>
<td>T50 = 7.323+360.161*age⁻¹</td>
<td>*** 0.703</td>
</tr>
</tbody>
</table>

***P<0.001
The graphs of male and female models were put on top of each other. The crossing age point for each partial time was calculated. The equation obtained was:

\[
\begin{align*}
\text{Male:} & \quad y_{\text{Male}} = a_1 + \frac{b_1}{\text{age}} \\
\text{Female:} & \quad y_{\text{Female}} = a_2 + \frac{b_2}{\text{age}}
\end{align*}
\]

\[\Rightarrow a_1 + \frac{b_1}{\text{age}} = a_2 + \frac{b_2}{\text{age}} \tag{3}\]

\[\text{age}_{\text{of cut}} = \frac{b_2 - b_1}{a_1 - a_2}\]

According to this equation and for each model of partial time the crossing age point was obtained (see Table 4). This shows differences in the development and when the boys begin to perform better than girls (see Figure 2).

Table 4. Crossing age point for each partial time

<table>
<thead>
<tr>
<th>Crossing age</th>
<th>ST</th>
<th>STT1</th>
<th>TT</th>
<th>STT2</th>
<th>T50</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST</td>
<td>10.61</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STT1</td>
<td></td>
<td>12.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT</td>
<td>12.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STT2</td>
<td></td>
<td>13.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T50</td>
<td>12.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DISCUSSION**

As was expected, the temporal analysis in a 50m freestyle test improves with age in the period of growth (see figure 3). The results obtained in percentages of RC times were different between genders and males had lower results than females. Our results showed significant differences between the percentages of younger swimmers from our study compared with internationals swimmers in all variables except in STT2. However, no differences were found from the data obtained in the percentage of TT (about 30%) by Thompson & Haljand (1997).

**CONCLUSIONS**

Race components change with the development of many physical fitness factors. With growth, the times of the swimmers studied have a tendency to come closer to the times of international swimmers. Temporal analysis has the same generic equation for boys and girls but there are two different models according to gender. The inverse function of the partial time by age and gender was the better approximation carried out in this training test of 50m freestyle. The times of girls are better than those of boys until the crossing age of about 12-14 years old.

**REFERENCES**


**ACKNOWLEDGEMENTS**

Esther Morales would like to thank the University of Granada for the grant that enabled her to carry out this research. She would also like to thank the Physical Education and Sports Department and the Research Group “CTS-527: Physical Activity and Sports in Aquatic Environment” of the University of Granada for the use of equipment and help in preparing this paper and the research on which it is based.
Regression Analysis Model Applied to Age-Group Swimmers: Study of Stroke Rate, Stroke Length and Stroke Index

Morales, E., Arellano, R., Femia, P., Mercade, J.

University of Granada, Spain

This investigation aimed to develop a regression model of the Kinematics Characteristics (KC) evolution in a large sample of regional age-group Spanish swimmers. Subjects were 280 regional swimmers selected from different clubs. The 50 m time, Stroke rate (SR), Stroke length (SL) and Stroke Index (SI) were used for analysis. Inverse function approximation of the race times by age (AGE) and gender (GEN) was carried out. Quadratic function approximation of the SL and SI by aging was carried out. Lineal function by aging was defined for ST. Furthermore, the analysis regression of KC for age and genders were calculated respectively. 50 m times were different between genders. There is a tendency to improve the parameters SL and SI with age in both genders. SR does not show a clear trend and has an irregular behaviour.

Key words: stroke rate, stroke length, stroke index, regression analysis, age-group.

INTRODUCTION

The swimmer’s time obtained after performing a competitive event can be considered as important information to help the coaching process that follows the competitive performance. The dynamic process of training needs as much information as possible from that performance. This information will help the coach to monitor the training program.

The Race Component (RC) Time to be included in the analysis of swimming performance during international swimming competition (Hay, Guimaraes, & Grimston, 1983) and it is very important to now the follow of race. In order to improve the swimmer’s efficiency stroke rate, stroke length and stroke index to be include in the analysis of competition.

Technical performance in cyclic activities and, more specifically, swimming performance (Hay, 2002) has traditionally been assessed by analysis the changes in and management of velocity, stroke rate and stroke length (Graig, & Perdergast, 1979; Pai, Hay & Wilson, 1984; Kennedy, Brown, Chegarlur & Nelson, 1990; Chegarlur & Brown, 1992; Chollet, Pelayo, Tourny, & Sidney, 1996). Several groups of researchers have analysed the technical and kinematics characteristics (KC), stroke rate (SR), stroke length (SL) and stroke index (SI), during international competitions to determine their relationship with performance.

Some studies have been published where regression equations were applied in the analysis of KC obtained in different competitions (Ab-saliamov & Timakovoy, 1090; Arellano, Brown, Cappaert & Nelson, 1996; Nomura, 2006). The study aim was to develop a regression model of the KC evolution in a large sample of regional age-group Spanish swimmers.

METHOD

The subjects were 280 swimmers (162 males and 118 females) regional swimmers. The age of these subjects ranged from 9 to 22 years.

The procedures that have been used to record the 50 m time and kinematics characteristics obtained by swimmers during the performance test of 50 m freestyle were: a) references were put on the swimming pool at the distances selected (5, 10, 15 and 20 m) to know when the head crossed this line; b) the 50m trials were recorded by five video cameras connected to a mini DV video recorder through a video-timer and video selector; c) all the images from the cameras were recorded at a distance of 8 m from the perpendicular line of the swimmer’s displacement (see figure 1).

The regression analysis was developed using the SPSS 17.0 statistical software (SPSS Inc., Chicago, Ill., USA). The Kolmogorov-Smirnov test showed the normal distribution of the sample. The regression analysis was used to discover the tendency and model of the 50 m time and KC. The regression analysis of the SL, and SI by age and GEN, and lineal function of the SR by AGE and GEN was carried out. Also, quadratic function approximation of the SL, and SI by age and GEN, and lineal function of the SR by AGE and GEN was carried out.

RESULTS

The T-test for independent samples explains the difference between genders for each KC (Table 1).

Table 1. T-test for independent samples according to gender in SR, SL and SI.

<table>
<thead>
<tr>
<th>Var.</th>
<th>Means</th>
<th>Difference</th>
<th>E.T</th>
<th>T (gl)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fc</td>
<td>Mas.</td>
<td>53.018</td>
<td>1.758</td>
<td>0.414</td>
<td>4.24 (787) ** 0.001***</td>
</tr>
<tr>
<td>Fem.</td>
<td>51.259</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lc</td>
<td>Mas.</td>
<td>1.427</td>
<td>-0.103</td>
<td>0.019</td>
<td>-5.33 (788) 0.001***</td>
</tr>
<tr>
<td>Fem.</td>
<td>1.530</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ic</td>
<td>Mas.</td>
<td>1.846</td>
<td>-0.179</td>
<td>0.045</td>
<td>-3.93 (782) ** 0.001***</td>
</tr>
<tr>
<td>Fem.</td>
<td>2.026</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*P<0.05; ** P<0.01; ***P<0.001 *Welch’s test

![Figure 1. Picture with the references and video cameras set-up on the swimming pool.](image-url)
The regression analysis was used to discover the tendency and model of evolution of 50 m time, SR, SL and SI according to age and gender. The type of equations obtained for gender in each partial time and event time can be observed in Table 2.

Table 2. Model of regression analysis of SR, SL and SI by age (AGE) and gender (GEN)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Model</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male Models</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR = 44.378+0.734*AGE</td>
<td>***</td>
<td>0.106</td>
</tr>
<tr>
<td>SL= -0.128+0.188<em>AGE+0.004</em>AGE²</td>
<td>***</td>
<td>0.480</td>
</tr>
<tr>
<td>SI= -1.782+0.405<em>AGE+0.007</em>AGE²</td>
<td>***</td>
<td>0.646</td>
</tr>
<tr>
<td>T50= 1.443+431.231*AGE⁻¹</td>
<td>***</td>
<td>0.647</td>
</tr>
<tr>
<td><strong>Female models</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR = 47.981+0.263*AGE</td>
<td>***</td>
<td>0.014</td>
</tr>
<tr>
<td>SL= -0.529+0.269<em>AGE+0.007</em>AGE²</td>
<td>***</td>
<td>0.542</td>
</tr>
<tr>
<td>SI= -2.978+0.643<em>AGE+0.018</em>AGE²</td>
<td>***</td>
<td>0.684</td>
</tr>
<tr>
<td>T50= 7.323+360.161*AGE⁻¹</td>
<td>***</td>
<td>0.703</td>
</tr>
</tbody>
</table>

***P<0.001

The diagram of dispersion of SR, SL and SI shows the evolution throughout the development. This evolution can be observed in Figure 2.

**DISCUSSION**

As was expected, the 50m time freestyle test improves with age in the period of growth. The results obtained in 50m times were different between genders and males had lower results than females. There is a tendency to improve the parameters SL and SI with age in both genders. Girls who get higher values in the SL and better IC. These data contradict the results obtained in different studies by Magischo (1993), Tella (1998), Sánchez (1999), who found higher values for men in SL and SI. With respect to the SR there exists a clear trend being boys obtaining higher values. The rejection of the clear model that corresponds to the SR supports studies on this variable and its evolution (Jähnig, 1987), thus confirming the absence of a pattern of evolution and consolidation of the variable from an early age.

Taylor et al. (2003) and Hellard et al. (2003) found a significant increase in the 50m swimming speed and a significant increase in strength in younger swimmers. These results confirm the relationship between growth, anthropometric and strength development and swimming efficiency. The kinematic variables SL and SI, evolve with age. SR is associated with progressive increase in arm span. Tella (1998) obtained increases in swimming speed associated with a significant increase in the size and strength levels. The SI to be the product of both (SI x speed swimming) follows the same behavior that they. The SR has an irregular behaviour (Tella, 1998; Vorontsov & Binevsky, 2003; Chollet, 2003; Caudal et al., 2003). SF changes made by the swimmers depend on the morphological differences, techniques and due to gender.

**CONCLUSIONS**

Kinematics components SL and SI change with the development of many physical fitness factors. With growth, the 50m times of the swimmers studied have a tendency to improve with the development. SR, SL and SI have the same generic equation for boys and girls but there are two different models according to gender. The inverse function by age and gender was the better approximation carried out in this training test of 50m freestyle. SR does not show a clear trend and thus confirming the absence of a pattern of evolution and consolidation of the variable from an early age.

**REFERENCES**


Hellard, P., Caudal, N., et al. (2003). Training, anthropometrics and performance relationships in French male swimmers of three age categories for 200 m events. Biomechanics and medicine in swimming IX.
Advanced Biomechanical Simulations in Swimming Enabled by Extensions of Swimming Human Simulation Model “SWUM”

Nakashima, M. \(^1\), Kiuchi, H. \(^1\), Maeda, S. \(^1\), Kamiya, S. \(^1\), Nakajima, K. \(^1\), Takagi, H. \(^2\)

\(^1\)Tokyo Institute of Technology, Tokyo, Japan
\(^2\)University of Tsukuba, Tsukuba, Japan

Since the authors presented the simulation model “SWUM” and its implementation software “Swumsuit” in BMS-2006, major extensions have been successively made on SWUM, such as optimizing calculation, musculoskeletal simulation, and multi agent/object simulation, in order to extend its capability of analysis. In this paper, these three extensions are explained and the various recent results from their implementation presented. The usefulness of the extensions was confirmed since many reasonable results were obtained.

**Key words:** Biomechanical Simulation, Optimization, Musculoskeletal model, SWUM

**INTRODUCTION**

There are many biomechanical problems to be solved in human swimming. In order to discuss such problems quantitatively, numerical simulation is becoming a powerful and useful tool. The authors have developed a simulation model, “SWUM,” (SWimming HUman Model) (Nakashima et al., 2007b) and a free software, “Swumsuit,” as the implementation of SWUM (Nakashima, 2005, 2006). By SWUM, it is possible to analyze the dynamics of the whole swimmer’s body with a short computation time due to modeling the fluid force acting on the swimmer. Since it was reported in the last symposium (Nakashima 2006), major extensions have been successively made on SWUM, such as optimizing calculation, musculoskeletal simulation, and multi agent/object simulation, in order to extend the capability of analysis. In this paper, these extensions are explained and the various recent results from them are presented in order to examine their usefulness.

**METHODS**

All analyses in this paper were carried out using SWUM. It was designed to solve the six degrees-of-freedom absolute movement of the whole swimmer’s body as a single rigid body by the time integration method, using the inputs of the swimmer’s body geometry and relative joint motion. The swimming speed, roll, pitch and yaw motions, propulsive efficiency, joint torques and so on, are computed as the output data. The swimmer’s body is represented by a series of 21 rigid body segments. Each body segment is represented by a truncated elliptic cone. The unsteady fluid force and gravitational force are taken into account as the external forces acting on the whole body. The unsteady fluid force is assumed to be the sum of the inertial force due to the added mass of the fluid, normal and tangential drag forces and buoyancy. These components are also assumed to be computable, without solving the flow, from the local position, velocity, acceleration, direction, angular velocity and angular acceleration for each part of the swimmer’s body at each time step. The coefficients in this fluid force model were identified using the results of an experiment with a limb model and measurements of the drag acting on swimmers taking a glide position in the previous studies (Nakashima et al., 2007b). For the simulation example of six beat crawl stroke in the previous study, the swimming speed of the simulation became a reasonable value, indicating the validity of the simulation model. With respect to the six beat crawl stroke, the authors have already analyzed contributions of each fluid force component and of each body part to the thrust, effect of the flutter kick, estimation of the active drag, roll motion, and propulsive efficiency (Nakashima, 2007a). Analyses of the other three strokes and comparison among four strokes...
necessary for the future task. The first extension made on SWUM was for the optimizing calculation. In the optimizing calculation, a single simulation of the time integration is repeated changing the design variables until a given objective function is maximized. For the design variables, all the input data, such as the body geometry of the swimmer and joint motion, can be employed. With respect to the objective function, the user can describe it freely using the output data, such as maximizing the swimming speed and maximizing the propulsive efficiency. As the optimizing algorithm, the Downhill Simplex method was employed. This extension has been implemented in Swumsuit version 2.0.0.

The second extension was the musculoskeletal simulation. In the musculoskeletal simulation, the human body is modeled as a series of body segments accompanying muscles modeled as wires. For the musculoskeletal calculation of the present study, commercial software, AnyBody Modeling System (AnyBody) (AnyBody Technology, Denmark) was employed. The whole body musculoskeletal model with 458 muscles shown in Fig. 1 was employed for the present study. With respect to the data connection between SWUM and AnyBody, the joint motion (relative body motion) is given as input data and the absolute movement of the whole body is calculated as output data in SWUM. These motion data are input into AnyBody. The fluid forces acting on swimmer are also input into AnyBody as external forces distributed on the swimmer’s body. This extension has been implemented in Swumsuit 3.0.0.

The third extension was “multi agent/object simulation.” “Multi agents” means multiple swimmers and “multi objects” means implements for swimming such as fins, a starting block, the pool wall, and so on. Before this extension, SWUM had been capable of analyzing one swimmer only by one simulation program. In the multi agent/object simulation, multiple simulation programs for multiple agents/objects run simultaneously to analyze. In addition to this, mechanical interaction among the agents/objects can be described freely by the user. For example, if the user would like to attach a fin to the swimmer, it can be simulated by locating a sufficiently strong “virtual” spring between the swimmer and fin. This extension has been implemented in Swumsuit 4.0.0.

With respect to the accuracy of simulation, it is difficult to estimate the general value for all cases. The validation study for each case will be necessary for the future task.

RESULTS AND DISCUSSION

The optimizing calculation for the trunk motion of the underwater dolphin kick has already been carried out by the authors (Nakashima, 2009). From this optimization, it was found that the obtained optimal motion which maximizes the propulsive efficiency is considerably similar to that of an elite athlete swimmer, in which the amplitude of the upper limbs’ displacement is small, the trunk moves as a ‘pitching seesaw’ with a node, and the lower limbs form a traveling wave. As the next application of the optimizing calculation, the optimization of arm stroke in the freestyle swimming has recently been tackled by the authors (Nakashima et al., 2009). In this optimization, the maximum joint torque characteristics were imposed, and the design variables were joint angles during the underwater stroke. As the next step, the optimization for more detailed maximum joint torque characteristics, which depend on joint angles and angular velocities, is now in progress. An example of its results is shown in Figure 2. In this optimization, the swimming speed was maximized under the constraints of the joint torque characteristics and the range of motion of the joints. Note that the time t was nondimensionalized by the stroke cycle. In order to reduce the calculation time, PSO (Particle Swarm Optimization) was employed as the optimizing method instead of the Downhill Simplex method. The dark lines emitting from the swimmer’s body represent the point of application, direction, and magnitude of the fluid force acting on the swimmer. It was found that the thrust by the hand had two clear peaks when pulling (t = 0.29) and pushing (t = 0.54) the water.

Next, the musculoskeletal simulation of the crawl stroke was carried out by Nakashima et al. (2007a). The simulation results of muscle activities were compared to those of an experiment in a previous study. It was found that most of the timings of the muscle activations in the simulation agreed with those in the experiment. The analyses of the other three strokes have also been conducted (Nakashima et al., 2008). Many reasonable tendencies were obtained in the simulation results. As a next step, the examination of quantitative accuracy of the simulation is now in progress. For this examination, the simulation results based on motion analysis data were compared with experimental EMG data, which were measured simultaneously with the swimming motion. An example of the simulated and experimental results is shown in Fig. 3. It was found that the swimming motion obtained in the experiment was represented well by the simulation. Note that the time t is nondimensional. It was also found that the upper limb muscles were activated during the hand stroke (Fig. 3(d)), and that the lower limb muscles were activated during the kick (Fig. 3(f)). If the accuracy of such musculoskeletal simulation becomes satisfactory, it will be greatly useful for the training and coaching of swimmers.

Figure 1. Whole body musculoskeletal model with 458 muscles employed for the musculoskeletal simulation.

![Figure 1](image1.jpg)

Figure 2. Simulation results of optimizing calculation (maximizing swimming speed under constraints with respect to joint torque characteristics).

Top: side view, bottom: bottom view.

![Figure 2](image2.jpg)

Figure 3. Results of musculoskeletal simulation and images in the experiment for the breaststroke.

![Figure 3](image3.jpg)

Figure 4. Simulation results of synchronized swimming by three swimmers.

![Figure 4](image4.jpg)
As an example of multi agents (multiple swimmers) simulation, simple synchronized swimming by three swimmers was simulated. In this simulation, three swimmers performed the flutter kick in order to obtain thrust and fluid force, which lifts the lower limbs. In order to represent hands grasping each other, virtual springs and dampers were employed. Animation images as the simulation results are shown in Fig.4. Note that the time $t$ is nondimensional. At the initial stage (Fig.4(a)), all the swimmers swim in the same direction. Due to the virtual springs and dampers attached to their hands, they gradually gathered (Fig.4(b)(c)). Finally, the swimmers’ upper limbs stably formed a hexagon (Fig.4(d)). This simulation was very simple since it was conducted for the demonstration. By carefully configuring the interactions among a larger number of swimmers, an entire simulation of a complicated team performance in synchronized swimming will become possible in the near future.

As an example of multi objects (a swimmer and multiple objects), monofin swimming was simulated. The monofin was divided into five rigid plates in this simulation in order to represent its elastic deformation in the sagittal plane. The truncated elliptic cones were employed in order to model the five rigid plates, and the plates were represented by flattening the cones. Virtual springs and dampers were employed in order to represent connections among the plates. In addition to these, rotational springs and dampers were also employed in order to represent the elasticity of the monofin itself. The animation images of the simulation results are shown in Fig.5. It was found that large fluid forces were acting on the monofin. In the near future, detailed simulation of the monofin swimming will be carried out.

As the third example of the multi agent/object simulation, the shooting motion in water polo was simulated. Animation images of the simulation results are shown in Fig.6. In this simulation, the swimmer’s hand and the ball were connected by a virtual spring and damper before the release of the ball. From the moment of release ($t = 0.68$), the spring and damper coefficients were set as zero. The ball was modeled as a series of four segments of truncated cones. From Fig.6, it can be found that the ball was smoothly released and flew in an appropriate direction. It was also found that a large fluid force was acting on the swimmer’s feet due to the breaststroke kick at the moment of release. The velocity of the shot ball was 13.5m/s.

**CONCLUSION**

In this paper, three extensions of the swimming human simulation model SWUM to the optimizing calculation, musculoskeletal simulation, and multi agent/object simulation were explained and various recent results were presented. The usefulness of the extensions was confirmed since many reasonable results were obtained. More detailed quantitative validation will be the future task. In future studies, various mechanical problems in swimming and aquatic activities will be analyzed by the present extensions.

**REFERENCES**


Influences of the Back Plate on Competitive Swimming Starting Motion in Particular Projection Skill

Nomura, T.¹, Takeda, T.², Takagi, H.²

¹Kyoto Institute of Technology, Kyoto, Japan ²University of Tsukuba, Tsukuba, Japan

The purpose of this study was to identify the influences of the back plate to competitive swimming starting motion in particular projection skill. Ten male college elite competitive swimmers performed the track start from the conventional platform and from the platform with the back plate. The influences of the back plate to competitive swimming starting motion in particular projection skill were identified as follows: (1) At the set position, the centre of mass displaced to a anterior position (-0.205±0.054 m); (2) The rear leg knee joint angle of the set position was about 90 degree (84.3±1.3 degree); (3) Just before take off, the body was accelerated into the horizontal direction (horizontal 0.16±1.13 m/s²); (4) At take off, the projection angle could be kept near horizontal (-8.2±5.2 degree); (5) There were no significant differences in flight phase.

Key words: Back plate block, Competitive swimming start, Projection skill

INTRODUCTION

A faster start has characteristics that move the centre of mass fast in the forward direction while the feet are in contact with the starting block, maximize the force exerted through the feet in the backward direction, and maximize the force exerted through the hands against the starting block in the forward and upward direction (Guimarães & Hay, 1985). Various investigations have been conducted on styles of set position as grab, track, handle, and so on (Banksby et al., 2002; Issurin & Verbitsky, 2003; Takeda & Nomura, 2006; Galbraith et al., 2008; Welch et al., 2008). They found that there was no significant difference of start time among the grab start, the track start, and the handle start. Furthermore, the 94% of variance in the start time was explained by the horizontal velocity at the entry. Furthermore, the horizontal velocity at entry results from the horizontal velocity at takeoff. Therefore, an important factor is the starting motion on the block to start fast. On the other hand, few studies have been considering the conditions of the starting block (Pereira et al., 2003). The starting platform with an adjustable back plate (posterior foot support) setting is approved by the international swimming governing body (FINA) in the facility rule 2.7. But there is no scientific evidence of the influences of the back plate on the performance of competitive swimming start. Therefore, the purpose of this study was to identify the influences of the back plate on competitive swimming starting motion in particular projection skill.

METHODS

Ten male college elite competitive swimmers were used as subjects in this study (Height = 177.5 ± 5.3 cm, Weight = 74.6 ± 8.4 kg, Age = 21.1 ± 1.3 yrs). The characteristics of subjects are showed in Table 1. Subjects performed the track start in two conditions. One trial started from the conventional platform (CON). The other trial started from the platform with the back plate (BKP).

The starting block specifications were as follows; Height from water surface was 0.75m. The conventional platform was 0.5m width × 0.7m length, with a 10° slope. As a back plate a pedal for a track and field's starting equipment was used. It was set 0.44m from the front edge of the platform, and with a 35° slope from the platform. A digital video camera equipment (FPS = 60Hz, Shutter speed = 250Hz) was connected to a starting and timing system and used to record the performance of each trial from a sagittal view. Seventeen calibration points were set over a 2.1m width × 2.5m height frame placed at the start area on the swimmer’s plane of movement. The digital video was analyzed by digitizing 13 points of the body: left finger tip, left wrist, left elbow, left shoulder, left hip, left ear, vertex, left knee, left ankle, left toe, right knee, right ankle, right toe. It was assumed that arm and torso were symmetrical. Kinematic variables were calculated using 2D-DLT method with a self-made motion analysis software (Note Player). The accuracy of coordinates was evaluated by the difference of the actual value and the estimated value (horizontal = 0.034m, vertical = 0.013m). Butterworth low-pass filter with a cut-off frequency of 6 Hz was used to remove noise from all raw data.

The objective in performing a swimming start while the feet are in contact with the starting block is to move the centre of mass (CM) as fast as possible in the forward direction. For the purpose of this study, the projection motion was divided into set position, acceleration phase, take-off and flight phase. The set position was a still position previous to the starting signal. The acceleration phase was from the starting signal until take-off. The take-off is the instant on time when the forward leg left from the block. The flight phase was defined from the take-off until the first contact with the water surface. Kinematic variables for the projection motion consisted of 15 items, as shown in Table 2 and Figure 1. The x-axis was defined to be the horizontal axis in the main plane of movement. The y-axis was defined to be the vertical one.

RESULTS

At the starting position, the coordinate of CM in BKP was (-0.205±0.054 m, 1.367±0.029 m). It was significantly forwarded and at a higher position than in CON (-0.253±0.054 m, 1.355±0.031 m). The knee joint angles of front and rear leg in BKP were respectively 140.1±5.7°, and 84.3±11.3°. The knees were extended significantly narrower than in CON (145.5±8.0° and 97.1±11.4°). The ankle joint angles of front and rear leg in BKP were, respectively, 140.6±8.4°, and 104.1±8.4°. The front ankle was dorsiflex significantly narrower than that in CON (147.1±10.5°). On the other hand, the rear ankle in

<table>
<thead>
<tr>
<th>No.</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
<th>Age (yrs)</th>
<th>Specialty</th>
<th>Distance (m)</th>
<th>Personal Best (min'sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>188.0</td>
<td>86</td>
<td>23</td>
<td>Free style</td>
<td>50</td>
<td>23.33</td>
</tr>
<tr>
<td>1</td>
<td>176.5</td>
<td>69</td>
<td>21</td>
<td>Butterfly</td>
<td>100</td>
<td>52.40</td>
</tr>
<tr>
<td>2</td>
<td>175.0</td>
<td>73</td>
<td>22</td>
<td>Breast stroke</td>
<td>100</td>
<td>1:01.51</td>
</tr>
<tr>
<td>3</td>
<td>175.8</td>
<td>81</td>
<td>21</td>
<td>Individual Medley</td>
<td>400</td>
<td>4:22.30</td>
</tr>
<tr>
<td>4</td>
<td>179.0</td>
<td>81</td>
<td>21</td>
<td>Free style</td>
<td>100</td>
<td>50.09</td>
</tr>
<tr>
<td>5</td>
<td>174.0</td>
<td>67</td>
<td>22</td>
<td>Free style</td>
<td>100</td>
<td>50.78</td>
</tr>
<tr>
<td>6</td>
<td>171.0</td>
<td>65</td>
<td>21</td>
<td>Butterfly</td>
<td>100</td>
<td>53.77</td>
</tr>
<tr>
<td>7</td>
<td>181.0</td>
<td>81</td>
<td>19</td>
<td>Breast stroke</td>
<td>100</td>
<td>1:01.78</td>
</tr>
<tr>
<td>8</td>
<td>172.0</td>
<td>62</td>
<td>19</td>
<td>Free style</td>
<td>200</td>
<td>3:59.38</td>
</tr>
<tr>
<td>9</td>
<td>183.0</td>
<td>81</td>
<td>22</td>
<td>Breaststroke</td>
<td>100</td>
<td>1:01.71</td>
</tr>
</tbody>
</table>
It was near to the zero than that in CON (-0.58±0.79 m/s²). At take-off, 136 CON (-8.2±4.3º). Mean horizontal acceleration in BKP was 8.76±0.87 was -6.7±4.4º. It was significantly nearer to the horizontal than that in

The force distribution on the starting block had reported that a
more preferable effect with back plate, because moving CM fast to the for-
toward direction was one important factor for a faster start (Guimarães et al., 2008). In the back plate condition, the rear knee joint angle obtained a value close to the 90º. The knee angle of the posterior leg was recommended 90º by a manufacturer of starting blocks with back plate that approved by FINA. However, isometric force-angle relationship of knee extension reported that higher force is produced at 105º to 120º than in other joint angle conditions (Lindahl et al., 1969). Moreover, the relationship isometric knee-hip extension force and the percentage of leg length that was criterion of the knee flexion had in-

The force distribution on the starting block had reported that a
more preferable effect with back plate, because moving CM fast to the for-
toward direction was one important factor for a faster start (Guimarães et al., 2008). In the back plate condition, the rear knee joint angle obtained a value close to the 90º. The knee angle of the posterior leg was recommended 90º by a manufacturer of starting blocks with back plate that approved by FINA. However, isometric force-angle relationship of knee extension reported that higher force is produced at 105º to 120º than in other joint angle conditions (Lindahl et al., 1969). Moreover, the relationship isometric knee-hip extension force and the percentage of leg length that was criterion of the knee flexion had in-

* p < 0.05, ** p < 0.01, *** p < 0.001

**DISCUSSION**

At the set position, the CM at the back plate condition is displaced to comparatively anterior position regarding the CON. It was in agreement with study of squatting-to-standing movement that heel elevation primarily influenced postural adjustment as anterior displacement of the hip (Sriwarno et al., 2008). In the back plate condition, the rear knee joint angle obtained a value close to the 90º. The knee angle of the posterior leg was recommended 90º by a manufacturer of starting blocks with back plate that approved by FINA. However, isometric force-angle relationship of knee extension reported that higher force is produced at 105º to 120º than in other joint angle conditions (Lindahl et al., 1969). Moreover, the relationship isometric knee-hip extension force and the percentage of leg length that was criterion of the knee flexion had in-vestedigated. The force exhibited a peak when the foot position was at 80-90% of leg length (Yamauchi et al., 2007). If this ratio was angle converted, it became about 100º to 120º. Therefore, at the set position in the back plate condition, the rear knee joint should be extended a little more. As a result, CM moved ahead slightly.

It seemed that the 0° before in BKP approached horizontally was a preferable effect with back plate, because moving CM fast to the forward direction was one important factor for a faster start (Guimarães & Hay, 1985). It was supported by Ax_before in BKP which was greater than one in CON and Ay_before in BKP was approximating to become zero. The force distribution on the starting block had reported that a higher force at last stage of the start movement, and force gradually became lower until take-off (Krüger et al., 2003). It was considered
that the cause that the body weight could not be supported by the leg because 0\,_{\text{take-off}} \text{ was about } 2^\circ \text{ lower than } 0_{\text{before}}.

There were a few influences of the back plate at take-off and during flight phase. The important aspect was that swimmers could improve with any technique with some intensive practice (Sanders & Bonnar, 2008). As subjects did not have an enough skill for using a back plate yet, they could not keep the domination on the starting block.

CONCLUSION
In conclusion, the influences of the back plate to competitive swimming starting motion in particular projection skill were identified as follows: (1) At the set position, the centre of mass displaced to a comparatively anterior position; (2) The rear leg knee joint angle at the set position was set at about 90\,^\circ; (3) Just before take-off, the body was accelerated into the horizontal direction; (4) At take-off, the projection angle could be kept nearer the horizontal. For a fast start, it is suggested that some intensive practice make best using of these advantages on the starting block.

REFERENCES
Issurin V., & Verbitsky O. (2003). Track start vs. grab start: Evidence before. The cause that the body weight could not be supported by the leg because 0\,_{\text{take-off}} \text{ was about } 2^\circ \text{ lower than } 0_{\text{before}}.

The aim of this study was to analyze the relationships between musical cadence and kinematical characteristics of a basic head-out aquatic exercise, when immersed to the breast. Six young women with at least one year of experience conducting head-out aquatic classes were videotaped in the sagital plane with a pair of cameras providing a dual projection from both above and underwater performing 5 incremental bouts (120 b.min\(^{-1}\), 135 b.min\(^{-1}\), 150 b.min\(^{-1}\), 165 b.min\(^{-1}\), and 180 b.min\(^{-1}\)) of the basic head-out aquatic exercise “rocking horse”. There was a decrease of the cycle period throughout the incremental protocol. Relationships between horizontal or vertical displacements with music cadence were not significant. On the other hand, increased cadence imposed increased segmental and centre of mass\' velocities. As a conclusion expert and fit subjects seem to increase segmental velocity with increasing musical cadence to avoid the decrease of the segmental range of motion.

Key words: head-out aquatic exercises, rocking horse, musical cadence, kinematics

INTRODUCTION
Massive research has been produced throughout the last decades in order to better understand the role of head-out aquatic exercises in populations' health (Barbosa et al., 2009a). Indeed, such studies aimed to characterize the physiological acute and/or chronic response of subjects performing head-out aquatic exercises. Moreover, the comprehensive knowledge about the biomechanical (i.e. kinematical) behavior performing this aquatic activity is quite reduced.

Conducting head-out aquatic exercise sessions, instructors often use the music cadence to achieve a pre-imposed intensity of exertion. Music cadences between 130 and 150 b.min\(^{-1}\) are suggested by technical literature for head-out aquatic exercises (Kinder and See, 1992). At least one empirical study reported that for healthy and physically active subjects instructors should choose music cadences between 136 and 158 b.min\(^{-1}\) (Barbosa et al., 2009b).

Increases in the music cadence imposes significant increases in the acute physiological adaptation (e.g., rate of perceived effort, heart rate or blood lactate) of the subjects (Hoshijima et al., 1999; Barbosa et al., 2009b). It is hypothesized that increased physiological response may be explained by the fact that increasing music cadence will also increase movement velocity and frequency, decreasing the segmental range of motion. However, to our knowledge there is no study in the literature reporting the kinematical changes imposed by an incremental cadence protocol at head-out aquatic exercises.

The aim of this study was to analyze the relationships between musical cadence and kinematical characteristics of a basic head-out aquatic exercise, when immersed to the xiphoid process (i.e., breast).

METHODS
Six non-pregnant, clinically healthy and physically active young women holding a graduation degree in Sports Sciences and at least one year of experience conducting head-out aquatic classes volunteered to participate in this study (23.67 ± 0.52 y-old; 57.42 ± 4.78 kg of body mass; 1.64 ± 0.07 m of height; 22.17 ± 2.56 kg.m\(^{-2}\) of body mass index).

Kinematical Characterisation of a Basic Head-out Aquatic Exercise during an Incremental Protocol

Oliveira, C. 1,4, Teixeira, G. 1,4, Costa, M.J. 2,4, Marinho, D.A. 3,4, Silva, A.J. 1,4, Barbosa, T.M. 2,4

1University of Trás-os-Montes and Alto Douro, Vila Real, Portugal 2Polytechnic Institute of Bragança, Bragança, Portugal 3University of Beira Interior, Covilhã, Portugal 4Research Centre in Sports, Health and Human Development, Vila Real, Portugal

The aim of this study was to analyze the relationships between musical cadence and kinematical characteristics of a basic head-out aquatic exercise, when immersed to the breast. Six young women with at least one year of experience conducting head-out aquatic classes were videotaped in the sagital plane with a pair of cameras providing a dual projection from both above and underwater performing 5 incremental bouts (120 b.min\(^{-1}\), 135 b.min\(^{-1}\), 150 b.min\(^{-1}\), 165 b.min\(^{-1}\), and 180 b.min\(^{-1}\)) of the basic head-out aquatic exercise “rocking horse”. There was a decrease of the cycle period throughout the incremental protocol. Relationships between horizontal or vertical displacements with music cadence were not significant. On the other hand, increased cadence imposed increased segmental and centre of mass\' velocities. As a conclusion expert and fit subjects seem to increase segmental velocity with increasing musical cadence to avoid the decrease of the segmental range of motion.

Key words: head-out aquatic exercises, rocking horse, musical cadence, kinematics

INTRODUCTION
Massive research has been produced throughout the last decades in order to better understand the role of head-out aquatic exercises in populations' health (Barbosa et al., 2009a). Indeed, such studies aimed to characterize the physiological acute and/or chronic response of subjects performing head-out aquatic exercises. Moreover, the comprehensive knowledge about the biomechanical (i.e. kinematical) behavior performing this aquatic activity is quite reduced.

Conducting head-out aquatic exercise sessions, instructors often use the music cadence to achieve a pre-imposed intensity of exertion. Music cadences between 130 and 150 b.min\(^{-1}\) are suggested by technical literature for head-out aquatic exercises (Kinder and See, 1992). At least one empirical study reported that for healthy and physically active subjects instructors should choose music cadences between 136 and 158 b.min\(^{-1}\) (Barbosa et al., 2009b).

Increases in the music cadence imposes significant increases in the acute physiological adaptation (e.g., rate of perceived effort, heart rate or blood lactate) of the subjects (Hoshijima et al., 1999; Barbosa et al., 2009b). It is hypothesized that increased physiological response may be explained by the fact that increasing music cadence will also increase movement velocity and frequency, decreasing the segmental range of motion. However, to our knowledge there is no study in the literature reporting the kinematical changes imposed by an incremental cadence protocol at head-out aquatic exercises.

The aim of this study was to analyze the relationships between musical cadence and kinematical characteristics of a basic head-out aquatic exercise, when immersed to the xiphoid process (i.e., breast).

METHODS
Six non-pregnant, clinically healthy and physically active young women holding a graduation degree in Sports Sciences and at least one year of experience conducting head-out aquatic classes volunteered to participate in this study (23.67 ± 0.52 y-old; 57.42 ± 4.78 kg of body mass; 1.64 ± 0.07 m of height; 22.17 ± 2.56 kg.m\(^{-2}\) of body mass index).
The protocol consisted of five bouts of 16 repetitions performing the basic head-out aquatic exercise “rocking horse” at the “water tempo” immersed to the xiphoid process (i.e., breast). Bouts intensity were 80 %, 90 %, 100 %, 110 % and 120 % of the cadence reported by Barbosa et al. (2009b) to achieve a 4 mmol.l⁻¹ of blood lactate, representing respectively 120 b.min⁻¹, 135 b.min⁻¹, 150 b.min⁻¹, 165 b.min⁻¹ and 180 b.min⁻¹ cadences. Musical cadence was controlled electronically by a metronome (Korg, MA-30, Tokyo, Japan) connected to a sound system.

The protocol was videotaped in sagittal plane with a pair of cameras providing a dual projection from both underwater (GR-SXM25 SVHS, JVC, Yokohama, Japan) and above (GR-SX1 SVHS, JVC, Yokohama, Japan) the water surface. The images of both cameras were recorded independently. The study comprised the kinematical analysis of the full cycles (Ariel Performance Analysis System, Ariel Dynamics Inc., USA) through a VCR (Panasonic, AG 7355, Japan) at a frequency of 50 Hz. Zatsiorsky’s model with an adaptation by de Leva (1996) was used with the division of the trunk in two articulated parts. To create a single image of dual projection as described previously (Vilas-Boas et al., 1997; Barbosa et al., 2005), the independent digitalization from both cameras was reconstructed with the help of a calibration object (0.675 x 0.855 m; 6 control points) and a 2D-DLT algorithm (Abdel-Aziz and Karara, 1971). For the analysis of the curve of the centre of mass’s kinematics a filter with a cut-off frequency of 5 Hz was used, as suggested by Winter (1990). For the segmental kinematics a cut-off frequency of 9 Hz was used, near to the value proposed by Winter (1990). A double-passage filtering for the signal processing was used.

The following variables were analysed: (i) cycle period; (ii) 2D linear position ranges (foot, hand and centre of mass), and (iii) 2D linear velocity ranges (foot, hand and centre of mass).

The normality of the distributions was assessed with the Shapiro-Wilk test. Linear regression equations models and its coefficients of determination were used to describe the relationships between musical cadence and biomechanical variables. The level of statistical significance was set at p ≤ 0.05.

RESULTS

Figure 1 presents a qualitative analysis from the centre of mass kinematics from a single subject during the second bout at 135 b.min⁻¹. Figure 2 displays the simple scatter gram from the cycle period according to the musical cadence imposed. There was a decrease of the cycle period throughout the experimental protocol (R² = 0.83; P < 0.01). Figure 3 and 4 presents respectively the overlay scatter gram for 2D displacement and 2D velocity according to the musical cadence imposed. There were non-significant relationship between horizontal (0.01 < R² < 0.31) or vertical (0.01 < R² < 0.03) displacements with the cadence imposed. On the other hand, for the horizontal and vertical velocities there were several significant relationships with the musical cadence. Increased cadence imposed increased centre of mass’ velocities for its horizontal (R² = 0.26; P < 0.01) and vertical components (R² = 0.41; P < 0.01), hand’s horizontal velocity (R² = 0.26; P < 0.01), foot’s horizontal (R² = 0.23; P = 0.02) and vertical (R² = 0.23; P = 0.01) velocities.

Figure 1. Qualitative analysis from the centre of mass’ horizontal displacement (panel A), vertical displacement (panel B), horizontal velocity (panel C) and vertical velocity (panel D) from a single subject performing the second bout at 135 b.min⁻¹.

Figure 2. Simple scatter gram from the cycle period according to the cadence imposed.

Figure 3. Overlay scatter gram from horizontal displacement and vertical displacement according to the cadence imposed.

Figure 4. Overlay scatter gram from horizontal velocity and vertical velocity according to the cadence imposed.
FIGURE 4. Overlay scatter gram from horizontal velocity and vertical velocity according to the cadence imposed.

**DISCUSSION**

The aim of this study was to analyze the relationships between musical cadence and kinematical characteristics of a basic head-out aquatic exercise, when immersed to the breast. Main data suggests that expert and fit subjects increase segmental velocity with increasing musical cadence to avoid the decrease of the segmental range of motion.

There was a very high relationship between cycle period and the cadence, with a decrease of the time variable throughout the incremental protocol. On one hand, there were no significant relationships between any of the displacement variables and the musical cadence. On the other hand, most of the velocity variables were moderate, positive and significantly related to the musical cadence.

Cycle period is considered as being:

$$ P = \sum_{i=1}^{n} t_i $$  \hspace{1cm} (1)

Where $P$ is the cycle period (in s) and $t_i$ is the duration (in s) of each phase, being the exercise composed by $i$ partial phases. The duration of each phase can be computed as:

$$ t_i = \frac{d_i}{v_i} $$  \hspace{1cm} (2)

Where $t_i$ is the duration of each partial phase of the exercise (in s), $d_i$ is the segment displacement (in m) during the partial phase and $v_i$ is the segment velocity (in m·s$^{-1}$) during the partial phase.

Although it was hypothesized in the introduction section that increasing cadence would impose a decrease of the segments range of motion; the subjects decreased the $t_i$ through an increase of the $v_i$. It can be speculated that this specific motor control, as well as, biomechanical strategy, can be related to the subjects’ profile. They were: (i) expert subjects, i.e., head-out aquatic exercise instructors that are aware from the need to maintain at all time a large range of motion performing basic exercises, independently from the cadence imposed and; (ii) very active subjects that not only are aware from this technical tips, but are also physically fit, allowing them to maintain such range of motion at different musical cadences.

As a conclusion, expert and fit subjects seem to increase segmental velocity with increasing cadences to avoid the decrease of the segmental range of motion.

**REFERENCES**


Influence of Swimming Speed on the Affected- and Unaffected-Arm Stroke Phases of Competitive Unilateral Arm Amputee Front Crawl Swimmers

Osborough, C.D. 1, Payton, C.J. 1, Daly, D.J. 2

1 Manchester Metropolitan University, Algher, United Kingdom
2 Katholieke Universiteit Leuven, Leuven, Belgium

The purpose of this study was to determine whether the arm stroke phases used by competitive unilateral arm amputee crawl swimmers differed between their affected and unaffected sides and whether these phases changed with an increase in speed. Thirteen highly-trained swimmers were video-taped underwater from two side-views during five increasingly faster 25 m front crawl trials. At all swimming speeds, the stroke phases of the affected and unaffected arms differed significantly. As speed increased, the duration of the affected-arm's Entry and Glide phase and the unaffected-arm's Pull phase decreased significantly; the duration of both arms' Push phase increased significantly. The amputees used a coordination strategy that asymmetrically adjusted their arm movements to maintain the stable repetition of their overall stroke cycle at different speeds.

Keywords: swimming; disability sport; Motor control; Biomechanics

INTRODUCTION

Stroke phases have been frequently used to describe the propulsive and non-propulsive arm actions of able-bodied front crawl swimmers. Maglischo et al. (1988) reported that while there were four propulsive phases in the front crawl underwater arm stroke action: (1) Downstroke; (2) Insweep; (3) Outsweep; and (4) Upsweep, able-bodied swimmers were unable to generate large propulsive forces in more than two of these phases. Later, Chollet et al. (2000), when formulating the Index of Coordination for front crawl, separated the complete action of the arm stroke cycle into four distinct phases: (A) Entry and Catch; (B) Pull; (C) Push; (D) Recovery, of which they assumed, B and C were propulsive and A and D were non-propulsive. For competitive swimmers with a single elbow-level amputation, the roles that the affected- and unaffected-arm have within the front crawl arm stroke cycle may differ from each other. It would be expected that the primary function of the unaffected-arm is to generate propulsion. However, uncertainty remains as to whether the affected-arm of a unilateral arm stroke phases has been undertaken with a single homogenous group of highly-trained swimmers with a single-arm amputation.

For unilateral arm amputee front crawl swimmers, increases in swimming speed are achieved by increasing stroke frequency (Osborough et al., 2009). However, it is unclear how these swimmers vary the duration of their arm stroke phases in order to accommodate an increase in stroke frequency and swimming speed. The purpose of this study was to determine if the arm stroke phases used by competitive unilateral arm amputee front crawl swimmers differed between their affected and unaffected sides and whether these phases altered with an increase in swimming speed.

METHODS

Thirteen (3 male and 10 female) competitive swimmers (age 16.9 ± 3.1 yrs) participated in this study. All participants were single-arm amputees, at the level of the elbow. The mean 50 m front crawl personal best time was 32.7 ± 3.1 s. Twelve of the swimmers competed in the International Paralympic Committee S9 classification for front crawl; one male swimmer competed in the S8 classification. The procedure for the data collection was approved by the Institutional Ethics Committee. All participants provided written informed consent before taking part in the study.

Participants completed five 25 m front crawl trials. Seven of the swimmers performed the trials from slow to maximum swimming speed (SSmax); the remainder performed the trials from maximum to slow swimming speed. To control for the effects of the breathing action on the swimming stroke, participants were instructed not to take a breath through a 10 m test section of the pool.

Two digital video camcorders (Panasonic NVDS33), sampling at 50 Hz with a shutter speed of 1/350 s were used to film the participants. Each of the camcorders was enclosed in a waterproof housing suspended underwater from one of two trolleys that ran along the side of the pool, parallel to the participants’ swimming direction. This set-up enabled the participants to be video-taped under the water, from opposite sides, over the 10 m test section.

The digital video footage was transferred to a laptop computer and analysed using SIMI Motion 7.2 software. Three consecutive, non-breathing stroke cycles for each participant, were then selected for analysis. The estimated locations of the gleno-humeral joint centre and the elbow joint centre of both the affected and unaffected arms were digitised at 50 Hz to obtain the angular position of the upper-arms, as a function of time. Before filming, the skin overlaying the joint centres was marked with black pen to help estimate their location.

At 80%, 85%, 90%, 95% and 100% of each participant’s SSmax, individual arm stroke phases, expressed as a percentage of the duration of the complete arm stroke cycle, were determined from the angle made by the shoulder-to-elbow position vector relative to the horizontal. Each upper-arm movement was divided into four phases (Fig. 1): Entry and Glide (A); Pull (B); Push (C); and Recovery (D):

(A) Entry and Glide: from where the elbow joint centre entered the water (0°) to where the shoulder-to-elbow position vector made an angle of 25° with the horizontal. This latter position corresponded to a point where typically the swimmers actively initiated extension of their affected-arm.

(B) Pull: from the end of the Entry and Glide (25°) to where the shoulder-to-elbow position vector made an angle of 90° with the horizontal.

(C) Push: from the end of the Pull (90°) to where the shoulder-to-elbow position vector made an angle of 155° with the horizontal. This latter position corresponded to a point where, as a result of the rolling action of the swimmers’ trunk and the bow-wave created by the swimmers’ movement through the water, the most-distal part of the swimmers’ affected-arm typically exited the water.

(D) Recovery: from the end of the Push (155°) to where the elbow joint centre entered the water (360°).

Figure 1. Divisions of the arm stroke phases: (A) Entry and Glide; (B) Pull; (C) Push; and (D) Recovery for a unilateral arm amputee front crawl swimmer.
Repeated measures general linear modelling tests were used to compare the changes in the relative durations of the Entry and Glide, Pull, Push and Recovery phases between the affected and unaffected arms and between the percentage swimming speeds. In all comparisons, the level of statistical significance was set at $p < .05$.

RESULTS

There were significant differences ($p < .05$) between the affected- and unaffected-arm for the relative durations of each arm stroke phase across the five percentage speed increments (Fig. 2). The affected-arm on average spent relatively longer in all arm stroke phases, with the exception of the Pull phase, when compared to the unaffected-arm. The mean relative duration of the Entry and Glide phase (A) for the affected and unaffected arms did not significantly change as the participants increased their swimming speed. While the unaffected-arm's relative Entry and Glide phase duration remained relatively constant ($23.2 \pm 8.0\%$ vs. $23.1 \pm 6.8\%$, for 80% and 100% of $SS_{\text{max}}$ respectively) with an increase in swimming speed, there was a slight reduction in the affected-arm's relative Entry and Glide phase duration between 80% and 100% of $SS_{\text{max}}$ ($38.3 \pm 9.5\%$ vs. $36.2 \pm 11.6\%$). The mean relative duration of the Pull phase (B) for the unaffected-arm, but not for the affected-arm, changed significantly ($p < .05$) as the participants increased their swimming speed. While the affected-arm's relative Pull phase duration remained relatively unchanged ($10.9 \pm 2.8\%$ vs. $11.0 \pm 2.3\%$, for 80% and 100% of $SS_{\text{max}}$ respectively) with an increase in swimming speed, there was a significant reduction ($p < .05$) in the unaffected-arm's relative Pull phase duration between 80% and 100% of $SS_{\text{max}}$ ($18.4 \pm 6.4\%$ vs. $13.8 \pm 2.7\%$ for the affected- and unaffected-arm respectively). At 100% of $SS_{\text{max}}$, the mean Pull phase durations were $19.4 \pm 5.3\%$ and $15.4 \pm 3.9\%$ for the affected- and unaffected-arm respectively.

The mean relative duration of the Recovery phase (D) for the affected and unaffected arms did not significantly change as the participants increased their swimming speed.

CONCLUSION

The results from this study show that at all swimming speeds the stroke phases of the affected and unaffected arms differed significantly. The affected-arm on average spent relatively longer in all arm stroke phases, with the exception of the Pull phase, when compared to the unaffected-arm. Such differences might be linked to how these swimmers learnt to organise the motor skills necessary to swim front crawl. As swimming speed increased the relative durations of certain arm stroke phases changed. With increasing speed: 1) the affected-arm's Entry and Glide phase decreased, while the unaffected-arm's Entry and Glide phase remained unchanged; 2) the unaffected-arm's Pull phase decreased, while the affected-arm's Pull phase remained unchanged; and 3) both arms' Push phase increased.

REFERENCES


**ACKNOWLEDGEMENTS**

The authors would like to acknowledge the following: British Disability Swimming for their support in this project; Professor Ross Sanders for the use of his facilities at the Centre for Aquatics Research and Education, The University of Edinburgh; and Miss Casey Lee for her assistance during data collection.

---

**Co-ordination Changes during a Maximal Effort 100 m Short Course Breaststroke Swim**

Oxford, S., James, R., Price, M., Payton, C.

1Coventry University, UK
2Manchester Metropolitan University, UK

The aim of the study was to establish the changes in co-ordination that occur during a 100 m breaststroke swim from a water start by: 1) measuring the kinematic changes that occur as the swimmer progressed through the four laps and, 2) analysing the co-ordination of the arms and legs (transition phase) corresponding to the time between the end of the leg propulsion and the start of the arm propulsion phases. Breaststroke participants (n=8, females and n=18, males) performed a 100 m maximal swim in a 25 m pool. They were recorded underwater using three 50 Hz cameras (one at each end of the pool and one mounted on a trolley). The last three strokes prior to turns were analysed. Significant changes in clean swim speed (p<0.05) were found between laps. Results indicate that participants reduce transition phase of the stroke to try and maintain clean swim speed.

**Key words:** Transition phase, stroke rate, stroke length, co-ordination

**INTRODUCTION**

In breaststroke swimming there are three main types of co-ordination used: 1) Continuous, which is characterised by the start of the leg kick following the end of the arm recovery; 2) Glide, which is characterised by a glide phase following the end of the arm recovery phase prior to the start of the leg kick; 3) Overlap, which is characterised by the initiation of the leg kick before the completion of the arm recovery phase (Maglischo, 2003). Investigation of co-ordination changes during a race could provide a better understanding of the swimmer’s personal co-ordination and how changes in that co-ordination relate to stroke rate, stroke length and swimming speed. Skilled swimming is inherently a rhythmic movement that involves stable and flexible modes of co-ordination between the arms and legs. These movements occur as a consequence of the interactions between the mechanical properties of the water and the intrinsic dynamics of the body (Seifert, Chollet and Bardy, 2004)

Swimming speed is directly affected by the athlete’s mechanical output (Toussaint et al., 1988) and fatigue has been defined as a decrease in the ability to maintain effective mechanical power output (Beelen and Sargeant, 1991). The majority of research that has looked at co-ordination changes has concentrated on the front crawl technique (Schmitzler et al., 2008; Seifert et al., 2007; Alberty et al., 2005). Alberty et al., (2005) showed a significant increase in the total relative duration of the propulsive phases from the 1st to the 4th 50 m during 200 m front crawl swimming. The authors reported that these increases in time spent in the propulsive phases of the stroke were a result of a decreased hand velocity, which in turn reduced the swimmer’s ability to generate propulsive forces when fatigued. The studies that have investigated changes in co-ordination in breaststroke swimming have all used a discontinuous graded protocol of 25 m (Seifert and Chollet, 2005; Chollet et al., 2004; Soares et al., 1999), assuming that the different speeds adopted by the participants correspond to speeds used during 50-200 m swims. These authors reported that increased velocity was associated with the shorter swim distances, which resulted in a significant reduction in the glide phase of the stroke.

A greater understanding of the co-ordination changes that take place during a swim and how fatigue affects these co-ordination changes would give sports scientists, coaches and swimmers an improved understanding of swimming performance. This information could help with the design of interventions (Pelayo et al., 2007) that allow participants to maximise their performance during training and in competition settings.
The aims of this study were to: (1) investigate co-ordination changes during a 100 m short course breaststroke swim and (2) compare kinematic variables between each of the four laps of the 100 m swim.

METHOD

Twenty-six specialist breaststroke participants (8 females: mean age, 19.1 ± 2.3 yrs; mean body mass, 70.0 ± 8.0 kg; mean height, 1.70 ± 0.05 m; 18 males: mean age 18.9 ± 2.2 yrs.; mean body mass 69.3 ± 7.3 kg; height 1.78 ± 0.06 m; short course 100 m breaststroke mean best times females 88.7 ± 5.4 s and males 77.0 ± 5.5 s) volunteered to participate in this study. The selection criterion for the study was that participants had to be competitive in the 100 m breaststroke event at County standard or above within that season. The study was approved by the Coventry University Ethics Committee. The requirements of the study were explained to participants and each participant provided written informed consent. Twelve body landmarks (lateral malleolus, lateral femoral condyle, greater femoral trochanter, styloid process, epicondyile of humerus and acromion process) were marked using black vinyl tape.

Each swimmer performed a self-selected 800 m warm-up in a 25 m pool. They were then instructed to perform a maximal effort 100 m swim from a water start without the use of race strategy. Three cameras operating at 50 Hz were used to record the 100 m swim. Two cameras (Sony video DCR-TRV460E) were submerged in waterproof housings, one at each end of the swimmer’s lane, to record frontal and rear views. The third camera, a waterproof bullet camera, was connected to a visual display unit (Sony digital video cassette recorder GV-D900E), which was attached to a trolley. The trolley was moved manually to maintain the swimmer’s hip marker in the centre of the visual display unit throughout the entire 100 m swim.

Time to complete 100 m was recorded via a video analysis package (Dartfish Trainer 2.5.2.19, Fribourg, Switzerland) as the time from when the feet left the wall at the start until the double hand touch on the wall at the end. Clean swim speed, stroke rate and stroke length were determined over a 10 m section of the pool that was not affected by starting, turning or finishing technique. The time taken for the hip marker to travel this 10 m distance from the 15 m marker to the 5 m marker from the end of the pool was determined from the video. Stroke length was calculated from the mean clean swim speed and stroke rates for each of the four laps, over the 10 m section of pool.

Stroke cycle time was calculated as the mean of the last three full strokes completed in the 10 m section of each lap from the frontal and sagittal camera views. To quantify co-ordination, five stroke phases were identified: 1) Arm Propulsion - from the initial separation of the arms from the extended position in front of the body until the first forward movement of the elbows when the hands were under the head; 2) Arm Recovery - from the end of the arm propulsion phase until the start of the separation of the hands from the extended position; 3) Leg Propulsion - from the start of the first backwards movement of the feet relative to the body (the point where the knees were maximally flexed at the start) until the instant when the knees were fully extended; 4) Leg Recovery - from the end of the leg propulsion phase until the frame prior to the first backwards movement of the feet in relation to the body; 5) Transition phase - from the end of the leg propulsion phase until the start of the arm propulsion phase. Each of the arm and leg phases were expressed as a percentage of a complete arm or leg stroke respectively. Transition phase was expressed as a percentage of a complete leg stroke.

The complete arm and leg strokes were calculated as the mean of three complete strokes. Means and standard deviations were calculated for all the data. Analysis of variance with Bonferroni post-hoc tests were used to compare laps (1, 2, 3 and 4) using selected variables at the same point of each lap (clean swim speed, stroke rate, stroke length, stroke cycle time, arm recovery, arm propulsion, leg propulsion, leg recovery and transition time). Correlation coefficients were determined among selected variables. The level of significance was set at p<0.05. SPSS 16.0 Software was used.

RESULTS

The mean performance time for the 100 m swim was 80.8 s ± 7.4. The performance time for 100 m showed a significant negative correlation (r = -0.86, p<0.05) with clean swim speed and a significant negative correlation (r = -0.57, p<0.05) with stroke length. There was no correlation between performance time 100 m and stroke rate or any of the phases of the stroke.

Table 1. Clean swim speed (CSS), stroke length (SL), stroke rate (SR) and 25 m performance times for each lap of the 100 m swim.

<table>
<thead>
<tr>
<th>Lap</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSS (m/s)</td>
<td>1.20±0.11*</td>
<td>1.10±0.09*</td>
<td>1.10±0.08*</td>
<td>1.10±0.10*</td>
</tr>
<tr>
<td>SL (m/cycle)</td>
<td>1.55±0.26</td>
<td>1.56±0.25</td>
<td>1.50±0.25</td>
<td>1.47±0.26</td>
</tr>
<tr>
<td>SR (stroke/min)</td>
<td>43.3±6.8</td>
<td>41.3±6.4</td>
<td>41.2±6.8</td>
<td>42.8±6.3</td>
</tr>
<tr>
<td>Time 25 m (s)</td>
<td>18.43±1.57*</td>
<td>20.37±1.66*</td>
<td>21.02±1.65*</td>
<td>21.44±1.87*</td>
</tr>
</tbody>
</table>

** , * (P<0.05) difference between laps.

Table 2. Duration of stroke phases expressed as a percentage; kick propulsion; kick recovery; arm recovery; arm propulsion and transition phase for each lap of the 100 m swim.

<table>
<thead>
<tr>
<th>Lap</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kick Propulsion (%)</td>
<td>23.9±5.3</td>
<td>23.9±7.0</td>
<td>23.5±6.4</td>
<td>24.9±8.1</td>
</tr>
<tr>
<td>Kick Recovery (%)</td>
<td>76.1±5.3</td>
<td>76.1±7.0</td>
<td>76.5±6.4</td>
<td>75.1±8.1</td>
</tr>
<tr>
<td>Arm Propulsion (%)</td>
<td>46.7±8.7</td>
<td>46.8±9.2</td>
<td>46.4±8.6</td>
<td>47.7±8.2</td>
</tr>
<tr>
<td>Arm Recovery (%)</td>
<td>53.2±8.7</td>
<td>53.2±9.2</td>
<td>53.6±8.6</td>
<td>52.3±8.3</td>
</tr>
<tr>
<td>Transition (%)</td>
<td>4.9±7.2</td>
<td>3.6±16.0</td>
<td>3.7±15.1</td>
<td>-0.5±7.0</td>
</tr>
</tbody>
</table>

There was no significant (p>0.05) change in any of the stroke phases with lap although transition time approached statistical significance (p=0.06) (Table 2). Transition time followed a similar trend to that of clean swim speed with a decrease of 8% from the 1st to the 4th lap. There was no significant change in stroke rate with lap (p=0.241) (Table 1) during 100 m swim. There was no significant change in stroke rate with lap although transition time approached statistical significance (p=0.06) (Table 2). Transition time followed a similar trend to that of clean swim speed with a decrease of 8% from the 1st to the 4th lap.

There was no significant change in stroke rate with lap although transition time approached statistical significance (p=0.06) (Table 2). Transition time followed a similar trend to that of clean swim speed with a decrease of 8% from the 1st to the 4th lap.

The remaining four participants changed from the glide to the overlap co-ordination throughout the 100 m swim. The remaining four participants showed no change in stroke length from the 1st to the 4th lap.

Table 2. Duration of stroke phases expressed as a percentage; kick propulsion; kick recovery; arm recovery; arm propulsion and transition phase for each lap of the 100 m swim.

<table>
<thead>
<tr>
<th>Lap</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kick Propulsion (%)</td>
<td>23.9±5.3</td>
<td>23.9±7.0</td>
<td>23.5±6.4</td>
<td>24.9±8.1</td>
</tr>
<tr>
<td>Kick Recovery (%)</td>
<td>76.1±5.3</td>
<td>76.1±7.0</td>
<td>76.5±6.4</td>
<td>75.1±8.1</td>
</tr>
<tr>
<td>Arm Propulsion (%)</td>
<td>46.7±8.7</td>
<td>46.8±9.2</td>
<td>46.4±8.6</td>
<td>47.7±8.2</td>
</tr>
<tr>
<td>Arm Recovery (%)</td>
<td>53.2±8.7</td>
<td>53.2±9.2</td>
<td>53.6±8.6</td>
<td>52.3±8.3</td>
</tr>
<tr>
<td>Transition (%)</td>
<td>4.9±7.2</td>
<td>3.6±16.0</td>
<td>3.7±15.1</td>
<td>-0.5±7.0</td>
</tr>
</tbody>
</table>

DISCUSSION

The primary aim of the study was to investigate the co-ordination changes during a 100 m breaststroke swim.

The results of the study show that thirteen of the participants...
utilised the glide co-ordination throughout the swim. The glide co-ordination is characterised by a positive transition time meaning that there is a delay from the end of the kick propulsion phase to the start of the arm propulsion phase. This corresponds to a period of no propulsion in the swimming stroke. The glide co-ordination is normally associated with swimming the 200 m breaststroke (Leblanc et al., 2009; Soares et al., 1999). Nine of the participants used the overlap co-ordination throughout the swim, which is characterised by a negative transition phase meaning that the arm propulsion phase starts before the end of the leg propulsion phase. Swimmers adopt this co-ordination pattern as it has been shown to reduce velocity fluctuations and helps maintain a higher mean velocity (Seifert & Chollet, 2005).

The transition phase changed in the majority of participants from the 1st to the 4th lap. Eighteen of the participants either increased the amount of overlap within their stroke (n=5), changed from glide to overlap co-ordination (n=5), or decreased the time spent in the glide phase of the stroke (n=8). The remaining participants altered their co-ordination in the other direction by increasing the amount of glide (n=8) thus showing an increase in transition time.

These changes in the participant’s co-ordination are likely to be a result of fatigue. Fatigue has been shown to hamper the sensorimotor system, affecting such functions as awareness, feedback and co-ordination, which maintain form and stability, resulting in the inability to maintain ideal mechanics (Toussaint et al., 2006). This means that as the participants become fatigued, as the race distance progresses, they change their co-ordination pattern therefore causing the participants to move towards or increase the overlap co-ordination in their stroke. These alterations in co-ordination could be a direct result of the participants trying to maintain homeostasis through compensatory mechanisms of the neuromuscular system to maintain effective mechanical power output. It is hypothesised that the results of the study suggest that the participants are becoming less mechanically efficient as the swim progresses as there is a significant decrease in clean swim speed from the 1st to the 4th lap and subsequent decreases in stroke length and stroke rate (table 1).

CONCLUSION

The findings of this study give us a better understanding of the effects of fatigue and the subsequent changes that occur in the co-ordination of the arms and legs in 100 m breaststroke swim.

As the participants fatigued they decreased the transition phase of the stroke by either increasing the amount of overlap or reducing the glide phase of the stroke in an attempt to maintain clean swim speed.

REFERENCES


The Effect of Angle of Attack and Depth on Passive Drag

Pease, D.L. 1, Vennell, R. 2

1Australian Institute of Sport, Canberra, Australia
2University of Otago, Dunedin, New Zealand

In order to quantify the effect of angle of attack and depth on drag force during underwater gliding the current study was undertaken. This aim was achieved by utilising a flume and an anatomically accurate mannequin whose orientation could be precisely controlled. Measurements were obtained with the mannequin oriented with the longitudinal axis at angles of attack of -4, -2, 0, +2 and +4 degrees relative to water flow. Measurements were taken at depths ranging from 0.2 – 0.8m and at velocities ranging from 0-2.55 m/s. There was generally little effect from the angle of attack other than near the surface (0.2m) where there was a tendency for the wave drag to be lower for the negative angles. This finding indicates that as swimmers approach the surface it may be beneficial to adopt a slight negative angle of attack in order to minimise the drag force.

Key words: swimming, passive drag, wave drag, angle of attack, flume

INTRODUCTION

Previous research into the drag forces (both active and passive) acting during human swimming has shown differences due to body size, shape, velocity and depth. However, one factor, which has not previously been investigated, is that of the angle of attack or pitch angle of the athlete’s body relative to the water flow. Angle of attack is a factor, which has been highlighted as an issue in previous study but due to the inability to systematically control this factor it has been generally described as a limitation.

Therefore, the present study was undertaken to try and quantify the effect of angle of attack on the drag forces acting upon a streamlined human swimmer by utilising an anatomically accurate mannequin whose orientation relative to the water flow direction could be precisely controlled.

It was hypothesized that, as angle of attack changed, there would be significant changes in the magnitude of the total drag force as well as changes in the relative contribution of the component forces, viscous, form, and wave drag. These changes would be primarily due to the changes in exposed frontal area with increasing (positive and negative) angles of attack away from the zero angle.

Based on the findings from previous research (Vennell, Pease, & Wilson, 2006) there are increases in the total drag force, and more specifically the wave drag contribution to that total force, as depth of the swimmer decreases. Therefore, another aspect of the current study was to examine the interaction between angle of attack and submergence depth and the measured drag force.

Previous studies have quantified body angles similar to angle of attack during free surface swimming (Zamparo, 2006; Zamparo et al., 2008) with the aim of using that angle as an indicator of body position. In general the angle of the trunk to the horizontal is used to represent angle of attack. In those studies body angles of approximately 15 degrees were found. However, during the streamlined portion of a swimming race when the athlete is fully submerged, and not moving on a fluid boundary, it was theorised that the angle of attack would be much less due to the freedom of the athlete’s body to move in the vertical as well as the horizontal plane. This is unlike surface swimming where the movement trajectory is fixed and essentially limited to the horizontal plane. By allowing for movement in the vertical plane as well as the horizontal, the trajectory of the centre of mass is more in line with the angle of the body thereby reducing the angle of attack relative to the surrounding water flow.

Therefore, the current study examined smaller angles of attack which may be achieved by fully submerged swimmers in a streamline position such as that experienced following starts and turns.

METHODS

All testing was conducted in the aquatic treadmill or ‘flume’ at the University of Otago, as described by Britton, Rogers, and Reimann (1998). In order to achieve the desired control over position of the body relative to water flow it was necessary to utilise an anatomically accurate mannequin rather than live subjects. The mannequin used was the same as that described in previous research (Bixler & Pease, 2006; Bixler, Pease, & Fairhurst, 2007; Vennell et al., 2006) and had a total surface area of 1.859 m² which allowed for the determination of an estimate for viscous frictional force.

The mounting structure used to support the mannequin was similar to that used in the previous studies. However, in the previous work the mannequin was mounted via a towing arrangement through the fingertips, which allowed for free movement of the rest of the mannequin’s body. Therefore a new mounting was necessary which allowed for the maintenance of orientation at all times. In the modified structure the mannequin is fixed directly to a vertical aerofoil spar, which is attached at the back of the mannequin. This aerofoil spar is then bolted to the same vertical pole and mounting structure described by Vennell et al. (2006). The vertical spar is infinitely adjustable in terms of mannequin depth between 0 and 0.9m. However, for the purposes of the current study the depths utilised were 0.2 – 0.8m at 0.1m increments. Depth was measured as the distance between the water free surface and the central longitudinal axis of the mannequin.

The vertical pole then was clamped to a horizontally oriented tri-axial load cell, AMTI model MC1-6-1000, with the Z axis parallel to the water flow direction. The load cell was in turn interfaced with an AMTI MCA6 amplifier and finally to a PowerLab unit which allowed for continuous data collection. Vertical position of the mannequins was controlled by raising or lowering the vertical spar and pole. The position was then fixed by a set screw at the gimbals and a scaffolding clamp attached in series with the tri-axial load cell.

In order to obtain the optimal drag–velocity curves for the mannequin, data was collected for 13 velocities: 0, 0.34, 0.55, 0.75, 0.95, 1.16, 1.36, 1.57, 1.77, 1.94, 2.15, 2.36, and 2.55 m/s respectively at each of the ten depths described previously. These conditions were repeated for each of the angles of attack; -4, -2, 0, +2, and +4° respectively. Angles of attack were based on a 0° orientation defined as that position with the minimum projected frontal cross sectional area. Six tests of five seconds in duration were undertaken for each test condition.

The projected frontal areas for these tested angles of attack were: 0.1282, 0.1156, 0.1079, 0.1124, and 0.1280 m² respectively. While attack angles greater than those tested may be exhibited in real situations, due to the uncertainty of the magnitude of load changes beyond the angles measured, limits were set in order to minimise the possibility of damaging either the mannequin or the testing support structure. Secondly, if angles greater than those tested had been utilised there would have been protrusion of the mannequin through the water surface at the minimum depth, which would have changed the wetted area and thereby affected the results.

In order to detect any effects of angle of attack on the drag forces, correlation coefficients were determined between the angles of attack and the respective drag force components. In order to utilise correlation analysis a linear relationship between angle of attack and drag was hypothesized due to the linearly decreasing depth of the leading edge of the mannequin. During the pilot testing the data were analysed for normality of distribution and were deemed to be suitable for parametric analysis. Due to the limitation of only utilising the single mannequin the magnitude of the correlation coefficient needed to be very high in order to achieve statistical significance (r ≥ .859 for significance at the 0.1 level and r ≥ .959 for significance at the 0.05 level).
RESULTS
The measured total drag force across all velocities at all depths for angles of attack of -4, 0, and +4 degrees respectively are presented in contour form in Figure 1. Contour plots of total drag force for all angles of attack with depth on the Y axis, velocity on the X axis and contours indicating drag force in Newtons. A) -4 deg B) 0 deg C) +4 Deg

Figure 1 Contour plots of total drag force for all angles of attack with depth on the Y axis, velocity on the X axis and contours indicating drag force in Newtons. A) -4 deg B) 0 deg C) +4 Deg
In order to assess the significance of the effect of angle of attack on the various drag forces experienced by the mannequin, Pearson correlation coefficients were determined between angle of attack and the respective drag force components at all tested depths and velocities. These correlation matrices are presented in Table 1.

Table 1 Correlation Matrices of angle of attack to; total drag (A) and wave drag (B) force at all depths and velocities. Correlations with significance of P<0.05 are highlighted in dark grey and those with significance of P<0.01 highlighted in the lighter grey.

### A. Depth

<table>
<thead>
<tr>
<th>Velocity</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.34</td>
<td>-0.002</td>
<td>0.413</td>
<td>0.012</td>
<td>0.087</td>
<td>0.457</td>
<td>-0.23</td>
<td>0.038</td>
</tr>
<tr>
<td>0.55</td>
<td>-0.457</td>
<td>0.021</td>
<td>-0.753</td>
<td>-0.549</td>
<td>0.083</td>
<td>-0.678</td>
<td>-0.601</td>
</tr>
<tr>
<td>0.75</td>
<td>-0.746</td>
<td>-0.772</td>
<td>-0.92</td>
<td>-0.891</td>
<td>-0.534</td>
<td>-0.702</td>
<td>-0.56</td>
</tr>
<tr>
<td>0.95</td>
<td>0.135</td>
<td>-0.8</td>
<td>-0.869</td>
<td>-0.966</td>
<td>-0.847</td>
<td>-0.988</td>
<td>-0.832</td>
</tr>
<tr>
<td>1.16</td>
<td>0.671</td>
<td>-0.682</td>
<td>-0.678</td>
<td>-0.89</td>
<td>-0.889</td>
<td>-0.932</td>
<td>-0.945</td>
</tr>
<tr>
<td>1.36</td>
<td>0.945</td>
<td>-0.465</td>
<td>-0.836</td>
<td>-0.941</td>
<td>-0.887</td>
<td>-0.958</td>
<td>-0.941</td>
</tr>
<tr>
<td>1.57</td>
<td>-0.72</td>
<td>0.498</td>
<td>-0.614</td>
<td>-0.739</td>
<td>-0.645</td>
<td>-0.93</td>
<td>-0.919</td>
</tr>
<tr>
<td>1.77</td>
<td>-0.808</td>
<td>-0.751</td>
<td>-0.911</td>
<td>-0.936</td>
<td>-0.831</td>
<td>-0.977</td>
<td>-0.931</td>
</tr>
<tr>
<td>1.94</td>
<td>0.728</td>
<td>-0.084</td>
<td>-0.454</td>
<td>-0.754</td>
<td>-0.589</td>
<td>-0.909</td>
<td>-0.932</td>
</tr>
<tr>
<td>2.15</td>
<td>0.929</td>
<td>-0.912</td>
<td>-0.904</td>
<td>-0.92</td>
<td>-0.882</td>
<td>-0.999</td>
<td>-0.98</td>
</tr>
<tr>
<td>2.36</td>
<td>0.958</td>
<td>-0.806</td>
<td>-0.695</td>
<td>-0.85</td>
<td>-0.962</td>
<td>-0.986</td>
<td>-0.96</td>
</tr>
<tr>
<td>2.55</td>
<td>0.928</td>
<td>-0.682</td>
<td>-0.382</td>
<td>-0.727</td>
<td>-0.886</td>
<td>-0.94</td>
<td>-0.915</td>
</tr>
</tbody>
</table>

### B. Depth

<table>
<thead>
<tr>
<th>Velocity</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.34</td>
<td>0.046</td>
<td>0.629</td>
<td>-0.052</td>
<td>0.044</td>
<td>0.38</td>
<td>-0.153</td>
<td>N/A</td>
</tr>
<tr>
<td>0.55</td>
<td>0.237</td>
<td>0.645</td>
<td>0.144</td>
<td>0.367</td>
<td>0.436</td>
<td>0.505</td>
<td>N/A</td>
</tr>
<tr>
<td>0.75</td>
<td>-0.05</td>
<td>0.079</td>
<td>-0.199</td>
<td>0.038</td>
<td>0.254</td>
<td>0.243</td>
<td>N/A</td>
</tr>
<tr>
<td>0.95</td>
<td>0.865</td>
<td>-0.174</td>
<td>-0.123</td>
<td>0.039</td>
<td>-0.07</td>
<td>0.266</td>
<td>N/A</td>
</tr>
<tr>
<td>1.16</td>
<td>0.947</td>
<td>0.471</td>
<td>0.321</td>
<td>0.601</td>
<td>0.383</td>
<td>0.55</td>
<td>N/A</td>
</tr>
<tr>
<td>1.36</td>
<td>0.979</td>
<td>0.603</td>
<td>0.101</td>
<td>0.2</td>
<td>0.227</td>
<td>0.241</td>
<td>N/A</td>
</tr>
<tr>
<td>1.57</td>
<td>-0.457</td>
<td>0.827</td>
<td>0.296</td>
<td>0.236</td>
<td>0.262</td>
<td>0.257</td>
<td>N/A</td>
</tr>
<tr>
<td>1.77</td>
<td>0.046</td>
<td>0.673</td>
<td>-0.067</td>
<td>0.075</td>
<td>0.309</td>
<td>0.064</td>
<td>N/A</td>
</tr>
<tr>
<td>1.94</td>
<td>0.841</td>
<td>0.953</td>
<td>0.323</td>
<td>0.177</td>
<td>0.478</td>
<td>0.33</td>
<td>N/A</td>
</tr>
<tr>
<td>2.15</td>
<td>0.958</td>
<td>-0.195</td>
<td>-0.385</td>
<td>-0.137</td>
<td>0.392</td>
<td>0.066</td>
<td>N/A</td>
</tr>
<tr>
<td>2.36</td>
<td>0.971</td>
<td>0.428</td>
<td>0.138</td>
<td>0.123</td>
<td>0.443</td>
<td>0.052</td>
<td>N/A</td>
</tr>
<tr>
<td>2.55</td>
<td>0.972</td>
<td>0.114</td>
<td>0.234</td>
<td>0.105</td>
<td>0.474</td>
<td>-0.257</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### DISCUSSION

As seen in Table 1 (A), there is a strong negative correlation at maximum depth, which then reverses and becomes positive at the minimum depth of 0.2m for total drag. When this is considered in conjunction with the results presented in Table 1(B), it is apparent that at the minimum depth the strong positive correlation between angle of attack and wave drag and the much greater contribution of wave drag to total drag, overwhelms the form drag component taking the total drag correlation to a strong positive condition.

The reason for the inverse correlations for wave drag and form drag is unclear. However, it is probable that as angle of attack increases the separation of the water flow from the mannequin occurs earlier as the fingertips move up into the flow. This earlier separation disturbs a greater water mass on the shallow side of the mannequin which therefore has greater interactions with the free water surface and therefore greater wave drag. In the negative pitch orientations this flow separation occurs on the deep side of the mannequin thereby reducing the surface interactions.

### CONCLUSION

Based on the results of this study there is evidence that a slight negative angle of attack, particularly when nearing the free water surface, may provide a reduction in the contribution of wave drag and therefore total drag, acting on the athlete. While the effect is small it may prove to be a performance enhancement. However, the effects of depth still far outweigh those of changing angle of attack. With total drag almost doubling as the free water surface is neared the greatest implication of this project is that athletes should try and stay below, at least, 0.6m for as long as possible during the performance of starts and turns. However, it is necessary to be shallower than this then it would be beneficial if the athletes adopted a slight negative angle of attack in order to minimise resistance.

An obvious limitation of this current study is the utilisation of only a single mannequin for the analysis. Additionally, while also providing advantages, the use of a rigid object as opposed to an articulated body is also a limitation. Therefore, the extrapolation of these results to all athletes must be done with caution until the findings can be confirmed on a greater number of subjects.

### REFERENCES


### ACKNOWLEDGEMENTS

The authors would like to acknowledge Speedo International for the use of the mannequin utilised in this study. In addition, thanks to Neil George and Glenn Braid for their assistance in establishing the testing rig.
Graphic Removal of Water Wave Impact in the Pool Wall during the Flip Turn

Pereira, S.M. 1,2, Gonçalves, P. 2, Fernandes, R.J. 2, Machado, L. 3, Roesler, H. 1, Vilas-Boas, J.P. 2

1University of the State of Santa Catarina, Florianópolis, Brazil
2University of Porto, Faculty of Sport, Cifs2d, Porto, Portugal

The aim of this study was to develop a graphical removal technique of the water wave that precedes the contact of the swimmer with the wall during the front-crawl flip turn, as well as to characterize and quantify it. To do this the researchers used an underwater force platform and two digital video cameras. In a pilot approach, a swimmer performed 8 turns without touching the wall. Following the pilot study, 17 swimmers of both genders, included the swimmer who participated in pilot approach, performed 154 complete flip turns. The water wave was removed graphically through a routine programmed in MatLab that was based on the symmetry of the wave, and the instant in time that the wave made contact with the wall. The average values for the maximum force of the wave were similar in both trials as well as to those previously published. Furthermore, the removal technique provided satisfactory results.

Key words: dynamometry, swimming, flip turn, wave measurement

INTRODUCTION

To move a body through the aquatic environment, swimmers transmit a volume of water that is explained by hydrodynamic drag. The volume of water depends, amongst other factors upon the swimmer’s body volume and the speed of travel (Barbosa & Vilas-Boas, 2005).

When the swimmer approaches the wall in the turn, some of the water volume displaced, hits the wall before the swimmer’s feet make contact. This anticipated force record makes it difficult to assess the real contact force of the swimmer. It is difficult to calculate the force generated by the wave and to remove it from the total force curve (Blanksby et al., 1998; Lyttle, 2000; Roesler, 2002).

Blanksby et al. (1998) were the first authors to recognize the presence of the bow water wave in the kinetic analysis of the turn in breast-stroke swimmers of different ages. These researchers tried to eliminate the wave’s effects through signal processing. However, as the frequency of the wave was similar to the frequency of the swimmer’s force signal, this was not possible to totally eliminate the bow wave without losing a considerable amount of useful data.

Lyttle and Mason (1997) attempted to explain the slope of the wave shape during the kinetic analysis of turns in front crawl and butterfly swimmers. The data at the instant in time that the swimmer touched the wall (instrumented with a 3D force platform) was recorded manually. The force records from the wave reached a maximum value of 500 N, and the duration of the wave was not mentioned. The authors concluded that the magnitude of this force was proportional to the size of the force platform since the force recorded by the wave should have been equal to the pressure generated, multiplied by the surface area of the force platform.

Roesler (2002) conducted a study using two force platforms, placed side by side on the wall of the pool, where the swimmer’s contact zone was only on one of the platforms. Recorded force peak values were around 371 N with a wave duration of around 0.14 s. The second platform, even without the swimmer’s contact, detected a load seven times smaller than the force produced by the wave on the first platform. This decrease was attributed to the distance that the wave travelled to reach the second platform.

The aim of the present study was to develop a graphical removal technique of the bow wave that precedes the contact of the swimmer with the wall during the front-crawl flip turn, as well as characterizing and quantifying it.

METHODS

In order to characterize and quantify the force-time curve produced by the wave before the turn, an extensometric underwater force platform was used, developed in accordance with Roesler (1997). Dimensions and characteristics were: 500 x 500 x 70 mm, load and sensitivity of 4000 and 2 N (respectively), natural frequency of 400 Hz, gain = 600. The force platform allowed data acquisition of force only in the perpendicular component to the surface of the platform. The platform mean measurement error was calculated after calibration and was given from the weighting values obtained from the platform and the real weight of dead-weights previously measured in a precision scale. The mean difference between the values acquired on the platform and the dead weights was less than 1%. The acquired signals were converted by an analog to digital (A / D) converter, with a 16 bit resolution (BIOPAC Systems, Inc.) and with input voltage of ± 10 volts. The acquisition rate was of 1000 Hz, powered by a 12 volts source, which allowed the subsequent import of the signal to a PC.

The platform was set in an upright position on the opposite wall of the starting blocks, in a metallic support that also included a stainless steel frame for improved comfort and safety of the swimmer. As the platform was 0.7 m apart from the turning wall, the black lines at the bottom of the pool were modified to fit the new setting, remaining at the official distance to allow normal turning performances.

Data from the force platform were acquired through the program AcqKnowledge * (BIOPAC System Inc.). Signal processing was programmed into a MatLab base and consisted of: calibration, filtering (Butterworth 4th order, with a cutoff frequency of 100 Hz) and DC offset removal. Normalization was done digitally by the program sharing files and turned over by the force of the weight of the swimmer.

Two video cameras were used to monitor the water and the swimmer movements, particularly the time of the initial contact of the swimmer at the force platform. A digital type HC-42E Sony camera was installed in a waterproof case (Sony SPK-HCB) and attached to the bottom of the pool perpendicular to the swimmers direction of movement (frontal to sagittal intermediate plan). A surveillance video camera (type B7W submersible camera - AC 230V) was fixed at the bottom of the pool, facing upward perpendicular to the swimming direction (frontal plan), in order to monitor the movement of the wave during the turn.

When the swimmer started swimming towards to the turning wall, a trigger was activated to the A/D converting system, which connected a underwater light visible by the video cameras. This process allowed synchronizing the video setup and the force records.

A male swimmer of 22 years old, 1.82 m in height and 84.9 kg body weight, finalist of sprint races at the Portuguese National Championships, performed 8 flip turns. He started from the center of the pool, 12.5 m apart from the turning wall, with maximum speed, but without touching the platform, as shown in Figure 1.
These trials allowed verifying that the force signal produced by the wave was reasonably symmetric (Fig. 3). In normal turning situations, swimmers touch the platform, allowing it to record the swimmer’s pushing action against the wall. However, as already stated, before the swimmer touches the wall, a water wave hits the platform being also recorded. To remove this extraneous force, two assumptions were made: (i) the wave force to time curve being symmetrical, and (ii) that the peak value of the water wave force occurs at the time instant of swimmer’s wall contact. From the force platform data was extracted the time of water wave force start, and from the image-based kinematics the time of swimmer’s first contact was obtained. We assume this to be coincident with half water wave curve. This half force to time curve of the water wave was then mirrored and its values were subtracted from the total force values registered by the platform (Fig. 2) to allow obtaining: (i) the swimmer’s contact force to time curve, and (ii) the water wave force to time curve.

It is possible to observe that the behavior of the curve is not linear but follows a pattern tending to a symmetrical condition, as observed before by Fujishima (1999). Mean results obtained for the quantitative parameters of the water wave obtained with the turns performed without touching the wall are presented in Table 1, as well as the data regarding eight turns from the same swimmer touching the wall and the 154 turns performed by the total sample of 17 swimmers.

Table 1. Mean values (Mean) ± standard deviations (SD) obtained for the variables: maximum and mean force value produced by the water wave, and wave impulse, grouped in normalized and absolute values in 3 situations of wave measurement during the flip turn.

<table>
<thead>
<tr>
<th>Turning trials</th>
<th>NORMALIZED VALUES</th>
<th>ABSOLUT VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximal</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>(N/bw)</td>
<td>(N/ bw)</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>8 turns without touching the wall</td>
<td>0.38 ± 0.77</td>
<td>0.16 ± 0.33</td>
</tr>
<tr>
<td>8 turns touching the wall</td>
<td>0.52 ± 0.12</td>
<td>0.24 ± 0.06</td>
</tr>
<tr>
<td>154 turns touching the wall</td>
<td>0.49 ± 0.24</td>
<td>0.19 ± 0.12</td>
</tr>
</tbody>
</table>

Figures 4 and 5 represent an example of the swimmer’s contact/impulse force to time curve, before (Fig. 4) and after removal (Fig. 5) of the water wave specific curve. In this case, the wave was almost fully incorporated into the swimmers’ contact curve, and the interference of the wave phenomenon into the swimmers’ kinetics is presumably important, making it more difficult to assess the effect of the wave over the impulse curve.

RESULTS
The force curves generated by the water wave obtained without the swimmer touching the wall resulted in a mean curve (Fig. 3).

![Figure 2](image2.png)

Solid line: force registered; dotted line: wave mirroring; vertical line: time of contact

Figure 2. Graphical representation of the removal of the water wave of the total force to time curve obtained during a crawl flip turn.

With a sample of 17 swimmers, 9 males and 8 females, aged 17.88 ± 3.19 years, height 1.73 ± 0.09, body mass 64.48 ± 11.90 kg, all participants at the Absolute Portuguese National Championships, 154 valid turns were analysed. The force to time curve produced by the water wave was eliminated graphically from the force to time curve produced by the swimmer’s contact. Moreover, the wave force to time curve was also treated to characterize their main characteristics. Descriptive statistics were used for data analysis.

![Figure 3](image3.png)

Figure 3. Mean force curve of the water wave generated by the displacement of the swimmer during the turn without touching the force platform.

![Table 1](image4.png)

Figure 4. Example of a force to time curve produced during a flip turn with the effect of the water wave impact.

![Figure 5](image5.png)

Figure 5. Example of a force to time curve produced during a flip turn without the effect of the water wave impact.
The comparison of the impulse (time integral of the force curve) with and without the water wave kinetic effect showed values of 314.48 ± 62.75, and 288.57 ± 51.79 Ns, respectively. This difference stresses out a reduction of 10.87% of the original force to time curve area when the water wave effect is removed.

DISCUSSION
The behavior of the force to time curve recorded at the turning wall due to the water wave produced by a swimmer is variable, and the factors that determine its behavior are not yet fully understood. Supposedly, they are likely related to the aided mass of water displaced with the swimmer, to its cross-sectional area, and to the speed and direction of its displacement.

The data collected during the turning experiments where the swimmer did not touch the wall are in agreement with Roesler (2002), but only partially with Lyttle and Mason (1997). In fact these authors found higher maximum values, but using a method in which the wave kinetics may include a not negligible contribution of the swimmers’ contact force (once the instrumentation that allowed the assessment of the initial contact instant was triggered manually). The possibly larger force plate used by these researchers might also influence the appropriateness of this comparison.

The kinetic characteristics of the water wave at the wall (mean data of 154 turns performed by 17 swimmers) were similar to those provided by the mean results of eight trials performed without contact at the wall by one swimmer, despite the diversity of individual responses. However, when comparing the results of the same swimmer touching or not the wall, it was observed that the water wave force values without touching the wall tended to be smaller, probably because the swimmer refrained himself in order to avoid touching the wall. Since he is one of the best and stronger swimmers of the sample, his results tended to be higher than those obtained for the global sample.

CONCLUSION
The comparison of the force to time curve characteristics of the water wave produced by a swimmer during a flip turn, with and without touching the wall, support satisfactorily the solution proposed to remove the water wave effect upon the swimmers’ kinetics. It can be accepted that the error associated with the wave data elimination through this procedure is not significant, ensuring data integrity of the swimmer’s kinetics at the wall, and allowing greater accuracy for its assessment.

REFERENCES
Lyttle, A. (2000). Hydrodynamics of the human body during the freestyle tumble turn. The University of Western Australia.


ACKNOWLEDGEMENTS
This work was supported in part by a grant of the FCT - Science and Technology Foundation, Portugal.
Extending the Critical Force Model to Approach Critical Power in Tethered Swimming, and its Relationship to the Indices at Maximal Lactate Steady-State

Pessôa Filho, D.M., Denadai, B.S.

Paulista State University, Brazil

This study aimed at comparing tethered-power (CP\textsubscript{Teth}), assessed using the critical force model, to the power at maximal lactate steady state (P\textsubscript{TethMLSS}), and critical velocity (CV) to the velocity at maximal lactate steady state (v\textsubscript{MLSS}). Ten swimmers were submitted to measurements of the CP\textsubscript{Teth} (linear and non-linear adjustments of impulse against time), CV (linear plotting of time and velocity in the 200, 400 and 800-m), P\textsubscript{TethMLSS} (3-4 trials ranging from 95 to 105% of non-linear F\textsubscript{crit}), and v\textsubscript{MLSS} (3-4 trials ranging from 85 to 95% of the 400-m free-crawl performance). Estimated CP\textsubscript{Teth} and P\textsubscript{TethMLSS} were obtained from the tethered-force equation times hydrofoil velocity. The results showed that neither CV (1.19 ± 0.11 m\textsuperscript{s}\textsuperscript{-1}) nor CP\textsubscript{Teth} (98±22W) matches the statements for maximal lactate steady-state (MLSS), once differences (p ≤ 0.05) were noted in relation to v\textsubscript{MLSS} (1.17 ± 0.10 m\textsuperscript{s}\textsuperscript{-1}) and P\textsubscript{TethMLSS} (89±15W), respectively.

Keywords: critical tethered-force; tethered swimming; maximal lactate steady state; swimming hydrodynamics

INTRODUCTION

Time to exhaustion is linearly related to the steady-load applied while swimming at full-tethered conditions (Ikuta et al., 1996). These authors defined critical force (F\textsubscript{crit}), the slope of the linear plot between impulse and maximal sustainable time, as the tethered force that could be maintained without fatigue. Despite the fact, that the measurements of endurance pulling force provide good relationships to long-distance performance (Swaine, 1996) and to blood lactate accumulation index (Ikuta et al., 1996), the relationship between pulling force and swimming intensity at maximal lactate steady-state (MLSS) remains to be established.

The MLSS corresponds to the highest constant workload that can be maintained over time without continuous blood lactate accumulation (Beneke et al., 2001). The time to exhaustion-based model is a simple, rapid and non-invasive test to evaluate endurance capacity, but the accuracy of indirect tests to estimate MLSS has been questioned. Dekerle et al. (2005) suggested that the determination of critical velocity (CV) leads to an overestimation of the metabolic rate associated with MLSS, and that the differences between these variables tend to be greater with the improvement of aerobic performance. Although Ikuta et al. (1996) did not measure the force or velocity at MLSS, they assumed its correspondence to the F\textsubscript{crit} based on the correlations between this parameter and endurance indices obtained under free swim condition.

It should be noted that the interchangeable use of MLSS and CV (or critical power, CP) to represent the upper limit of heavy exercise domain has been refuted either in cycling (Pringle & Jones, 2002) or in swimming (Dekerle et al., 2009). Despite the slight differences between these variables, CP leads to an overestimation of physiological rate associated to MLSS (Pringle & Jones, 2002; Dekerle et al., 2003). Thus, it was postulated that exercising just above MLSS is hardly tolerable once it induces to a continuous increasing in blood lactate concentration and VO\textsubscript{2} (Pringle & Jones, 2002; Dekerle et al., 2009). Nevertheless, this slight difference between MLSS and CV (or PC) should be interpreted with caution, due to methodological limitations of modeling CV (or PC) (Dekerle et al., 2003) and of the precise control of load under MLSS testing procedures (Pringle & Jones, 2002).

The assessment of stroke force by means of tethered swimming is simple and versatile, besides it has provided a great deal of specificity for swimmer evaluation, training and free swimming performance (Johnson et al., 1993; Rouaud et al., 2006). Furthermore, according to Kendle & Thorsvald (2006), force measurement with tethered swimming is highly reliable and shows low values of variation for test-retest protocol. Thus, assuming tethered swimming as a steady-force environment, one of the purposes of this study was to compare and to relate the values of power output at MLSS (P\textsubscript{TethMLSS}) in relation to the critical force (F\textsubscript{crit}) model. Another purpose was to proceed with the same analysis for reciprocal tests under free crawl swimming, allow for further comparisons through the two swimming conditions (non- and full-tethered), as for blood lactate concentration at MLSS, and for amplitude of the differences between P\textsubscript{Teth} vs. P\textsubscript{TethMLSS} and velocity at MLSS (v\textsubscript{MLSS}) vs. CV.

METHODS

Ten well-trained male swimmers (16.6 ± 1.4 years, 69.8 ± 9.5kg, 175.8 ± 4.6cm) were submitted to four independent tests in order to measure the P\textsubscript{Teth}, CV, P\textsubscript{TethMLSS} and v\textsubscript{MLSS}. They were informed of all test protocols and we obtained their informed consent. The study was approved by the local Ethics Committee.

The active drag force (F\textsubscript{A}) in maximal free crawl swimming was estimated based on subjects body mass, using drag proportionality coefficient (A = ((0.35 x mass)) + 2), according to Toussaint et al. (1998). This procedure is not a direct measurement of active body drag, and it takes into account an early assumption that the resistance is related to the square of the swimming velocity (F\textsubscript{A} = Av\textsuperscript{2}) (Toussaint et al., 1998). On a practical note, this approach provides a good deal of applications for hydrodynamics assessment on poolside throughout the training season.

To estimate F\textsubscript{crit}, loads ranging from 75 to 100% of the Fr in the pulley-rope system were attached to the swimmer. Three trials lasting 3 to 15 minutes were performed until exhaustion, i.e. the instant that the swimmer was not able to generate force enough to prevent him from being pulled back by the load. The impulse (load times trial duration, N\textsubscript{s}) was plotted against trials duration by means of a linear curve fitting (i = a + b(t)), and a non-linear two-parameter equation (t = a/(i – b)), where the slope gives F\textsubscript{crit} in both adjustments (Ikuta et al., 1996). The load related to MLSS intensity was obtained in three to four trials ranging from 95 to 105% of non-linear F\textsubscript{crit}. The greatest fraction that did not elicit a lactate accumulation above 4mM/L\textsuperscript{2} between 10\textsuperscript{th} and 30\textsuperscript{th} minutes was considered the tethered-force at MLSS (F\textsubscript{TethMLSS}). Blood samples (~25µl) from ear lobe were analyzed for lactate concentration ([La]) using an automated analyzer (YSI 2300, Yellow Springs, Ohio, USA). The test was interrupted by 30s break for blood sampling at the 10\textsuperscript{th} and 30\textsuperscript{th} minutes, as suggested by Beneke et al. (2001).

To approach mechanical tethered-power (P\textsubscript{Teth}) from F\textsubscript{crit} and F\textsubscript{MLSS} we considered two assumptions. First, the hydrofoil moves backward forces in steady state equals:

\[ F_{\text{Load}} = F_{\text{Teth}} = 0.5C_x \rho u \times S_{\text{Hyd}} \times u^2 \]  

(1)

where F\textsubscript{Load} and F\textsubscript{Teth} are noted in Newtons; C\textsubscript{x} is the drag coefficient for hydrofoil (~2.2), \rho is the water density (~1000kg/m\textsuperscript{3}), S\textsubscript{Hyd} is the hydrofoil plane area (estimated from hand and forearm volume powered by two thirds, i.e. V\textsubscript{Hyd} \times 0.67), and u is the squared hydrofoil velocity (v\textsubscript{Hyd} m\textsuperscript{s}\textsuperscript{-1}). The volume of hand and forearm was determined...
A positive relationship was analyzed in all endurance variables (Table 2). The amount of mechanical power used beneficially to the stroke task of overcome steady-load resistance was:

\[ P_{\text{Teth}} (W) = F_{\text{Teth}} (N) \times v_{\text{Hydro}} (~m\cdot s^{-1}) \] \hspace{1cm} (3)

Further, the \( P_{\text{Teth}} \) and \( P_{\text{TethMLSS}} \) were obtained by inserting \( F_{\text{crit}} \) and \( F_{\text{MLSS}} \) into Equation 2 and thereafter to Equation 3.

Test protocols in free style swimming:
Swimming crawl velocity correspondent to MLSS was determined from three to four trials in the range of 85 to 95% of the 400 meters velocity. The CV was obtained from linear adjustment of the free-crawl time performance in the 200, 400 and 800 meters, following the model \( v_{\text{Lim}} = \frac{(F_{\text{Load}}/0.5C_x\text{Hydr} \times \rho \times S_{\text{Hydr}})^{1/2}}{2} \) (Dekerle et al., 2005).

Statistical analysis:
The Pearson's coefficient provided the correlation among variables, and the difference between them was designed by test-T for paired data. Bland and Altman analysis was applied to compare the endurance index obtained from the models. The level of significance was \( p \leq 0.05 \).

RESULTS
Active drag value corresponded to 26.41 ± 3.34\(^2\) at 1.63 ± 0.07\(m\cdot s^{-1}\) freestyle velocity. For comparison between time-based protocols in free and tethered swim conditions (Figure 1), a range of ~85 a 100%Fr\(_{\text{max}}\) was closely related to exhaustion range ~3 to 12 min \((r^2 = 0.973)\). It was in the same order to the association observed between velocity performance and 200, 400 e 800-m distances \((r^2 = 0.975)\). However, dissimilarities were observed between higher and middle intensity efforts of the protocols \((p = 0.000 \text{ and } p = 0.045\,)\, respectively), but not between long-lasting and low intensity ones \((p = 0.449)\).

The critical force, and associated mechanical power have shown to be different from both tethered-force and mechanical power at MLSS (Table 1). Critical velocity has no similarity to velocity at MLSS either. Difference of blood lactate concentration between paired trials of each test condition (tethered and free swimming) was noted as significant \((p = 0.0002)\, \text{ and } (p = 0.038)\) ones (Figure 2). However, lactate concentration at MLSS did not differ in all test protocols \((p = 0.448\) for blood concentration of 3.84 ± 0.60mmol.L\(^{-1}\) and 3.61 ± 0.97mmol.L\(^{-1}\) in the tethered and free swim, respectively). Also, a strong positive relationship was analyzed in all endurance variables (Table 2).

Figure 2: Lactate profile in the bouts of either protocol to determine MLSS intensity: swimming velocity (dotted lines and filled symbols) and tethered-force (continuous lines and open symbols). Marked differences were significant at the end of trials \((p = 0.05)\, \text{between each of the low (') and middle (') intensities across protocols.}

Table 1: Pearson's Coefficient of the velocity and mechanical endurance variable.

<table>
<thead>
<tr>
<th>(v_{\text{MLSS}} ) (m(\cdot)s(^{-1}))</th>
<th>(v_{\text{PFcrit}} ) (m(\cdot)s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.0</td>
<td>50.4</td>
</tr>
<tr>
<td>50.4</td>
<td>46.5</td>
</tr>
<tr>
<td>46.5</td>
<td>45.2</td>
</tr>
<tr>
<td>45.2</td>
<td>44.5</td>
</tr>
</tbody>
</table>

**DISCUSSION**
Blood lactate concentration, in both tethered and non-tethered test conditions, are in agreement with the value of 3mmol.L\(^{-1}\), which has been suggested by Takehashi et al. (2009) as a suitable value for MLSS in swimming. Velocity \(1.24 \pm 0.11m\cdot s^{-1}\) and lactate concentration \(2.8 \pm 1.2mmol.L^{-1}\) reported by Dekerle et al. (2005) for MLSS in freestyle conditions, are also not dissimilar from those showed in the present study.

Despite the fact that subjects could swim at different levels of lactate steady-state the first two trials, when both protocols are compared, the physiological intensity at MLSS did not differ in tethered and free swimming conditions, which is in agreement with the concept that MLSS depends on the motor pattern of the exercise (BENEKE et al., 2001). Therefore, the lack of statistical difference between blood lactate concentration at MLSS into tethered and non-tethered swimming conditions suggest that the mode of exercise and metabolic profiles are similar.

Results from tethered-force vs. time adjustments given a slope value \(5.63 \pm 0.80kg\) were close to that \((6.87 \pm 1.02kg)\) originally reported by Ikuta et al. (1996). Submaximal reference of mechanical tethered-power is not available. Swaine (1994) evaluated endurance power in swim-bench reporting 115.4 ± 14.8W. From another study, Swaine (1996) reported values of 120.7 ± 9.4W for the slope of the relationship between total work done and time-limited in swim-bench. Toussaint et al. (1998) did estimate critical power during freestyle by plotting energy...
cost against time performance in six distances, yielding 114.5W. These references are out of range for tethered-power at MLSS, but are approached to the range of tethered-power at Fcrit (P_{Fcrit}).

The estimated powers (P_{Fcrit} and P_{TMSS}) are related, but statistically different, as the relationship observed to CV and v_{MLSS} in non-tethered crawl. Dekerle et al. (2005) also found significance for difference between v_{MLSS} and CV in swimmers, despite the good relationship (r = 0.87) between these variables. Also, the physiological responses when swimming 5% below and 5% above CV are those characterizing the heavy (sustainable steady-state) and severe (non-sustainable) intensity domain, whiling responses at CV lies within severe domains (Dekerle et al. 2009). These results support the conclusion that CP and MLSS do not represent the same physiological parameter, whilst associated work-rate seemed to be correlated among group of trained athletes (Pringle & Jones, 2002; Dekerle et al., 2005). It should be pointed out that power parameters obtained from tethered swimming protocols further increase the dissociation between the MLSS and CP, and the interindividual differences for these variables. Otherwise, tethered swimming may be considered a reasonable ergometer to access aerobic endurance capacity based on both invasive (lactate concentration profile) and non-invasive (time to exhaustion model) methods, since it ensures a force controlling environment that is a requirement for MLSS and CP protocols.

Moreover, the differences in power output at tethered and non-tethered swimming seems to corroborate the conclusion of Dekerle et al. (2003) that the accuracy and reliability for evaluation of aerobic endurance relies on MLSS determination, despite PC practicality. Nevertheless, the optimization of training adaptation requires the definition of work-rate clusters of common profile of physiological response among subjects. Whether physiological response at VC (or PC) and at MLSS provides or not a common reference of exercise intensity, it remains to be elucidated.

Neither CV nor the mechanical power at Fcrit matches the assumption for MLSS, the highest constant intensity that can be maintained without progressive increases in blood lactate concentration over time. Thus, the interchangeable use of these parameters seems to be unreliable. However, further research about physiological contextualization of the mechanical power output at Fcrit and at MLSS must take into account the technical ability of moving forward. This would improve the usefulness of data when assessing exercise tolerance, assisting in planning and predicting performance in swimming.

ACKNOWLEDGEMENTS
The authors wish to thank the subjects who agreed to participate in the study, and FUNDUNESP (00155-09/DFP) for the funding support.

REFERENCES


Preliminary Results of a “Multi-2D” Kinematic Analysis of “Straight- vs. Bent-arm” Freestyle Swimming, Using High-Speed Videography.

Prins, J.H., Murata, N.M., & Allen, J. S. III.

University of Hawaii. U.S.A.

Synchronized, high-speed digital cameras were used for underwater videotaping of swimmers, each of whom were required to perform a series of trials with both bent-arm and straight-arm pull patterns. The resulting video footage was digitized and processed using “Multi 2-D” motion capture software. Results demonstrated (1) The advantages of using high-speed videography for quantifying swimming stroke mechanics. (2) The resulting data provided insight into the relationship between the varying degrees of elbow-bend during the pull cycle, and fluctuations in linear hip and wrist velocities.

Key words: Freestyle stroke mechanics; High-speed videography; motion analysis.

INTRODUCTION

The accessibility of high-speed digital cameras, coupled with the ability to synchronize the video output from multiple cameras, has made it possible to analyze swimmers in more detail. Motion analysis software makes possible the kinematic analysis of the resulting video footage. One area of interest is the perceived outcomes between a “bent-arm” vs. “straight-arm” underwater pull in Freestyle (Front-Crawl) swimming. Following the success of a select number of Olympic finalists who have used a straight-arm Freestyle arm recovery, there is now a question of whether a straight-arm recovery, coupled with a similarly straight underwater pull leads to the generation of increased propulsive forces. The purpose of this paper is to describe the preliminary results of a kinematic analysis of the straight-arm vs. bent-arm underwater pull, using selected variables of these two types of pull patterns.

METHODS

Four members (age = 19.4 +/- 0.8 yr; height 183 cms +/- 6.2 cms) of the Men’s University of Hawaii “Division I” Intercollegiate swimming team participated in this pilot study. Each swimmer was filmed for a total of 6 trials, during 3 of which they were instructed to maintain their natural bent elbow position (B.A.), followed by 3 trials using a straight-arm (S.A.) underwater pull. Subjects were asked to swim at a pace as close as possible to their best 200 meter swimming time. Two high-speed digital cameras (Basler Model A602f), installed in custom housings, were mounted to rigid frames which themselves were anchored to the pool deck. The cameras were placed at a depth of 0.3 meters, each at right angles to each other for frontal and lateral viewing. The cameras were controlled via dual cabling from a desktop computer located on the pool deck. One cable was assigned for camera control via Firewire (IEEE 1394), the second cable was used for camera frame synchronization. Frame rate was set at 100 frames/second.

Rotational joint segments were identified using a series of light emitting diodes (LEDs) housed in waterproof housings. The LEDs were taped to the body and were powered by a battery pack attached to a belt worn by the swimmer at the waist. Calibration was conducted using a 4-point frame (1m x 1m), located in the plane of motion.

Motion analysis software (Vicon Motus, Denver, CO), was used for video capture, data analysis, and generating reports. The software includes a “Multi 2-D” (M2-D) feature, which enables multiple cameras to be synchronized. Each sequence was digitized using a combination of auto-tracking and manual modes.

RESULTS

Following video capture and digitizing, the following variables were measured using the Motus software: (1) Degree of elbow-bend; (2) Linear velocities of the hip in the sagittal plane (X-axis); (3) Linear velocities of the wrist in the sagittal (X), Vertical (Y), & the Resultant (R), directions; (4) Angular velocities of the wrist as measured from the shoulder. A composite of the data is presented in Table 1.

Table 1. Data shows Degree of Elbow Bend, Linear Hip and Wrist Velocities & Angular Wrist Velocities as a function of Elbow Positions.

<table>
<thead>
<tr>
<th>Degree of Elbow Bend (degrees)</th>
<th>Hip Velocities (LVH) - X-axis (m/sec)</th>
<th>Wrist Velocities (LWV) - Y-axis (m/sec)</th>
<th>Wrist Velocities (LWV) - R-axis (degrees/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Bent Arm Pull</td>
<td>134</td>
<td>X – 1.41 to 2.31</td>
<td>Y – 1.36 to 2.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R – 1.70 to 2.73</td>
<td></td>
</tr>
<tr>
<td>Straight-Arm Pull</td>
<td>178</td>
<td>X – 1.78 to 2.52</td>
<td>Y – 1.36 to 2.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R – 1.70 to 2.53</td>
<td></td>
</tr>
</tbody>
</table>

DISCUSSION

The study focused on two areas of interest: First, was the adoption of high-speed video technology coupled with motion analysis software to capture and analyze the underwater pull patterns of swimmers. The second area of interest was the possible interaction between the degree of elbow bend during the underwater pull, and linear changes in wrist and hip velocities in the primary plane of motion.

The decision to use the “Multi 2-D” (M2-D) feature incorporated into the software was made because it provided a means of monitoring selected kinematic parameters, specifically the potential changes in hip velocity as a function of underwater elbow flexion. In spite of the inherent limitations of 2D vs. 3D analyses, the M2-D feature was designed with gait analysis in mind, i.e. placing the cameras at right angles to each other, making it ideally suited for observing swimming stroke mechanics. The second innovation, i.e. designing and implementing a system of waterproof LED’s that were taped to the swimmer’s joint segments, proved invaluable for digitizing the resulting footage.

With respect to the ability to film at higher frame rates, the results were immediately apparent. Past experience using cameras that were limited to standard frame rates (30 fps or 60 fields/sec) consistently produced blurring of the hands, particularly at the end of the pull, the phase referred to as the “follow-through”. As anticipated, these distortions are amplified with the caliber of swimmer being filmed. By increasing the frame-rate to 100 fps, there was a significant change in the image quality, which allowed the automatic digitizing feature incorporated in the software to work function effectively.

After the resulting data was filtered and processed, two primary observations emerged. The major observation was the manner in which the linear hip velocity (LHV) changed over the duration of the underwater pull cycle. Figure 1 is a sample report that combines the lateral synchronized video frame with two graphs that plot LHV and LWV in the plane of motion as a function of “time”. The vertical line in the two graphs is a feature of the software, which allows the synchronization of each video frame with the respective time intervals on the selected graphs.

Figure 1. Synchronized video frame combined with linear variations in “hip & wrist velocity”, each plotted as a function of “time”.

Figure 2. Composite data for four members of the University of Hawaii’s Division I swimming team, showing the measured kinematic variables of elbow bend, hip and wrist velocities.
Independent of whether they were swimming with "bent" or "straight" arms, "peak" LHV for all 4 swimmers, occurred approximately midway through the stroke, i.e. when the hands were passing underneath the vertical line of the shoulder. When the linear wrist velocity (LWV) was combined with this data it was evident that peak LWV slightly preceded "peak" LHV.

The second observation was the relatively smaller difference between the degrees of elbow-bend when the subjects were asked to swim with "normal strokes", as compared to consciously pulling with "straight-arms". Tradition has dictated that we recommend maximum elbow-bend close to 90 degrees, when the hands pass vertically below the line of the shoulders. However, the subjects in the study held their arms at a more obtuse angle, the measured range for these 4 subjects being between 121 and 134 degrees. Determining whether these elbow positions are coincidental, or a trend, will have to wait for an increase in subject number as the study is continued.

CONCLUSION
Given the chronological constraints for manuscript submittal, and the time needed for familiarization of the equipment described in the study, this manuscript should be treated as an introduction into the utilization of improved technology for studying swimming stroke mechanics. Although the small subject number produced no measurable differences, either within or between subjects, when swimming with either BA and SA positions, what was intriguing was the consistent positions of the arm, during the underwater pull cycle, where maximum hip velocity was produced. In time, by increasing the number of subjects and refining the testing protocols, the expectation is that we will continue to open new avenues of research in swimming biomechanics.

REFERENCES

Biomechanical Factors Influencing Tumble Turn Performance of Elite Female Swimmers

Puel, E. 1, Morlier, J. 1, Cid, M. 1, Chollet, D. 2, Helfard, P. 3

1Laboratoire de Mécanique Physique, CNRS UMR 5469, Université Bordeaux 1, France
2Centre d’Études et Recherches, Fédération Française de Natation, Paris, France
3Département d’Études et Recherches, Fédération Française de Natation, Paris, France

The aim of this study was to examine the effects of kinematic and dynamic parameters on the turn performance (3mRTT). Eight elite female swimmers were analysed during a crawl tumble turn at maximum speed. The movements were filmed using 5 underwater cameras and a 3D force platform recorded wall forces. Results showed that the time of maximum horizontal force and the glide duration were related to the performance criterion. The best female swimmers were able to develop maximal horizontal force earlier during the push-off phase. Further studies with an extended population (male and less-skilled female swimmers) would analyse the effects of more parameters, especially from the contact phase.

Key words: Swimming, Kinematics, Dynamics, Turn, Performance

INTRODUCTION
In elite swimmers, only few opportunities are available to improve performance. Swimming performance can be defined as the time taken to complete a race. It can be subdivided into starting, stroking and turning.

Turns represent a paramount factor for determining the final performance of a swimming race. Blanksby et al. (1996) and Cossor et al. (1999) reported significant correlations with 50 m freestyle times and both 2.5 m (r = 0.72 to 0.85) and 5 m (r = 0.90 to 0.97) round trip times (RTT). In addition, Blanksby et al. (1996) found that the fastest and slowest young female swimmers differed significantly between the 50 m and these two measures of turning performance (2.5m and 5m RTT). Chow et al. (1984) found that the correlation between the total turn time and the event time increased with the distance of the event. It is noticeable too that turning is faster than stroking (Blanksby et al., 1996 and 2004).

A successful swim turn results from a multitude of factors and requires a complex series of moves to optimise the total turning performance. The freestyle tumble turn can be divided in the approach, rotation, wall contact, glide, underwater propulsion, and stroke resumption phases. For the contact phase, Prins and Patz (2006) distinguished passive (“braking”) and active (“push-off”) sub-phases. Lyltte et al. (2000) studied gliding position and kicking technique and established an optimal range of speeds (1.9 to 2.2 m/s) at which to begin underwater propulsion in order to prevent energy loss from excessive active drag.

The first aim of this study was to analyse relations with both kinematic and dynamic factors from each phase and the 3 m round trip time (3mRTT) as measure of turning performance. The second aim was to develop a model for performance using a stepwise multiple regression.

METHODS
Eight elite female swimmers participated in this study (Table 1).
Table 1. Swimmer’s general characteristics (n = 8, SD: standard deviation, WR: world record, PB: personal best).

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Body mass (kg)</th>
<th>Height (cm)</th>
<th>200 m freestyle WR / PB (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>22.3</td>
<td>62.2</td>
<td>174.7</td>
</tr>
<tr>
<td>SD</td>
<td>4.1</td>
<td>6.2</td>
<td>5.8</td>
</tr>
</tbody>
</table>

The swimmers were analysed during a crawl tumble turn at maximum speed, when passing through a specific pre-calibrated space with mean dimensions of 4.2 x 1.1 x 1.9 m for the horizontal (main movement direction), vertical (pool depth) and lateral (lane width) directions, respectively placed in contact with the turning wall and the water surface. Five stationary mini-DV video cameras (Sony DCR-HC62E and DCR-HC96E) were located underwater at different depths in waterproof cases. The angle between axes of adjacent cameras was approximately 45° and the five cameras were located on a semi-ellipse centred on the turning wall. Twelve to 14 calibration points were used, and the synchronization of the images was obtained using an underwater strobe flash (Epoque ES-150 DS α) visible in the field of each video camera. An underwater piezoelectric 3D force platform (Kistler 9253B12) was also mounted on the turning wall recording at a frequency of 2000 Hz. One complete turn was analysed for each swimmer. The testing session took place in a 50 m indoor pool.

The anatomical reference points of interest were digitized manually, frame by frame (at a frequency of 50 Hz). The points digitized for each camera were: centre of the skull (head), shoulders, elbows, wrists, finger-tips, hips, knees, ankles and tibiotarsus. Image coordinates were transformed to 3D object-space coordinates using the Direct Linear Transformation algorithm (Abdel-Aziz & Karara, 1971). Reconstruction precision of calibration points was 14.1 ± 9.1 mm with a maximal error of 42.8 mm. Missing coordinates were interpolated by a cubic spline function and then smoothed by the Savitzky-Golay filtering method (interpolation order: 2, window size: 13).

The kinematic data were the horizontal velocity of the head at the beginning of the turn (when the head was 3 m before the wall, VIn in m/s), 1 m before the rotation phase (V1mR in m/s), at the beginning of the rotation phase (VR in m/s), at the maximum horizontal force peak (VPe in m/s), at the end of the push-off (VG in m/s), at the end of the glide (VOu in m/s) and at the end of the turn (when the head was 3 m after the wall, VOut in m/s). The delimitation between the approach and the rotation phase was determined when the swimmer increased her head depth (vertical displacement). The horizontal position of the head when rotation began was also computed (RD in m). The end of the push-off (synchronisation point with dynamic data) and the delimitation between the glide and the underwater propulsive phase was obtained by observing video data. This time ended the glide duration (GT in s).

The dynamic data recorded were: maximum horizontal force peak (Pe in N) and final contact time (synchronisation point with kinematic data). Vertical and lateral forces helped to discern the first contact time and the delimitation between the braking and the push-off phases. PeT (in s) was the time between the beginning of the push-off and the maximum horizontal force peak. %PeT (in %) was the ratio between PeT and the push-off duration (PeT in s).

Pearson correlation and linear regression tests were used to identify the relationships among the tumble turn performance criterion (3mRTT as the time taken to swim from 3 m in to 3 m out the turning wall, in s) and both kinematic and dynamic factors. The level of significance was set at 95 % (p<0.05).

RESULTS

The best model was 3mRTT = 0.817 x GT + 0.155 x PeT + 2.464 (F = 38.1, r² adj = 0.91, p < 0.001).

DISCUSSION

The major aspect of this study was that the best female swimmers (with turning time as criterion of performance) were able to develop their maximal horizontal force earlier during the push-off phase. This result should be compared to the model of Klauck (2005) who presented that a later maximal horizontal force leads to a maximal speed at the end of the push-off phase. No significant correlation existed between VG and PeT. Klauck suggested that peak force should occur close to the end of the push-off i.e. at full leg extension. This model could be discussed about its biomechanical pertinence. Takahashi et al. (1983) reported indeed that the knee joint was at about 120° of flexion when peak force was observed during the push-off phase of the tumble turn. These researchers also stated that peak force during the vertical jump was observed at a similar range of motion (120-140°). Hence, Blanksby et al. (1996) suggested that coaches should implement leg strength and power programmes to decrease the time to achieve peak force.

The correlation between 3mRTT and V1mR showed that increasing speed at the start of the turn tended to decrease the time taken to complete the turn. This idea is well accepted by swimmers and coaches who claim to "attack" the wall.

A stepwise multiple regression was computed to seek the best possible predictors of the 3mRTT. The results indicated that the best predictors were GT and PeT. The role of PeT was discussed just above. It could be surprising that 3mRTT and GT were showing the same tendencies: shorter glide resulted in a better turn. Lyttle et al. (2000) established an optimal range for VU and only one of our swimmers ended gliding above these speeds.
CONCLUSION
The purpose of this study was to examine the effects of kinematic and dynamic parameters on the crawl tumble turn performance. Results showed that the time of maximum horizontal force is preponderant. The glide phase is also critical. In the future, it would be interesting to analyse the effects of more computed parameters, especially during the contact phase (e.g. impulses and push-off angles) and to extend the population (recreational female swimmers and elite male swimmers). More subjects with the same protocol may help to provide a deeper understanding of turning performance and develop a new hypothesis about the swimming level (which could affect the ability) or the gender (which could have an effect upon physical factors).

REFERENCES

ACKNOWLEDGMENTS
The authors wish to thank Michel Knopp and Nicolas Houel from the French Swimming Federation (F.F.N.) for their contribution during the data acquisition process.

Front Crawl and Backstroke Arm Coordination in Swimmers with Down Syndrome

Querido, A. ¹, Marques-Aleixo, I. ¹, Figueiredo, P. ¹, Seifert, L. ², Chollet, D. ², Vilas-Boas, J.P. ¹, Daly, D.J. ³, Corredera, R. ¹, Fernandes, R.J. ³

¹University of Porto, Faculty of Sport, Cifisd, Portugal
²University of Rouen, Faculty of Sport Sciences, France
³Katholieke Universiteit Leuven, Faculty of Kinesiology and Rehabilitation Sciences, Belgium

The aim of this study was to characterize the Index of Arm Coordination (IdC) in swimmers with Down syndrome (DS). The IdC for the front crawl (N=6) was -11.3% ± 5.2% and for the backstroke -13.5 ± 4.8%. This indicates that all swimmers demonstrated a catch-up mode coordination in both strokes. Swimmers with DS did not adapt their arm coordination as usually occurs in swimmers with higher level of proficiency. In front crawl significant positive correlations were found between IdC and the push phase as well as the propulsive phase. An inverse correlation was found between IdC and the non-propulsive phase. In backstroke, the catch-up coordination mode was used by all swimmers. In this study hand lag time values far above those of elite swimmers were observed. There was an inverse relationship between IdC and velocity.

Key words: Down syndrome, arm coordination, front crawl, backstroke

INTRODUCTION
Although cyclic activities, such as swimming, have traditionally been assessed by velocity, stroke rate and stroke length, recent studies have shown that the evaluation of arm coordination provides new information to the classic analysis (Chollet et al., 2008). For assessing arm coordination, Chollet et al. (2000) proposed the Index of Coordination (IdC), which seems to give relevant information on a swimmer’s skill. In the alternating strokes, i.e. front crawl and backstroke, arm coordination is quantified as the time between propulsive phases of the right and left arms, i.e., by the time lag between the propulsion moments of consecutive strokes. According to Chollet et al. (2000), three possible modes of coordination can be found: (i) catch-up, with significant discontinuity between propulsion moments of both arms (IdC < 0%); (ii) opposition, showing continuity between propulsive phases of both arms (IdC = 0%) and (iii) superposition, in which overlapping of propulsive phases is seen (IdC > 0%).

Studies focusing specifically on swimmers with Down syndrome (DS) are very scarce. Since individuals with DS typically have a combination of physical and cognitive limitations that significantly affect their motor performance and contribute to a high variability of their motor behavior (Epstein, 1989; Lahtinen, 2007), it is important to understand if these typical characteristics, such as lower muscular strength, higher percentage of body fat and anthropometric traits are reflected in their inter arm coordination. The purpose of this study was therefore to characterize the IdC in alternating strokes performed by swimmers with DS, as well as to establish the relative duration of the propulsive and non-propulsive phases.

METHODS
Six international level swimmers with DS volunteered to participate in this study (age: 20.2 ± 4.8 years, height: 154.3 ± 12.1 cm, weight: 58.4 ± 14.1 kg and fat mass: 16.4 ± 11.6 %). The participant’s guardians provided informed written consent to take part in the study, which was approved by the local ethics committee.

All swimmers performed 2 x 20 m swims at maximal intensity, the
first in front crawl (non-breathing cycles) and the second in backstroke. Two digital cameras (Sony DCR-HC42E), placed inside a sealed housing (SPK - HCB), recorded two complete underwater arm stroke cycles in the lateral and frontal views. The lateral camera was placed at a depth of 2 m and 11.5 m from the lane in which the participant swam. The frontal camera was placed at 0.5 m depth. A rigid calibration frame (2.10x0.70 m) was recorded at the beginning of the trials for calibration purposes. Subsequently, each frame (50 Hz) was digitized manually using the APASystem (Ariel Dynamics Inc., USA). Nine anatomical points were used: the hip (femoral condyle), and on both sides of the body, the longest finger tips, wrist, elbow and shoulder of each swimmer. After bi-dimensional reconstruction using a DLT procedure (Abel-Aziz and Karara, 1978), a low pass filter of 5 Hz was used.

The front crawl arm stroke was divided into four phases (Chollet et al., 2000): (i) entry and catch (time between the entry of the hand into the water and the beginning of its backward movement); (ii) pull (time between the beginning of the hand's backward movement and when it reaches a vertical plane with the shoulder); (iii) push (time from the position of the hand below the shoulder to its release from the water) and (iv) recovery (time from the point of water release to water re-entry of the arm, i.e., the above water phase). In backstroke, each arm stroke was divided into 6 phases (Chollet et al., 2006): (i) entry and catch (time between the entry of the hand into the water and the start of its backward movement that is followed by a diagonal hand sweep); (ii) pull (time between the beginning of the hand’s backward movement and when the line shoulder-hand is at 90° to the truck); (iii) push (time from the point hand at shoulder level and the end of the hand’s backward movement); (iv) hand lag time (time during which the hand stops at the thigh before the push phase and before starting to move upward to clear the water); (v) clearing (time from the beginning of the hand release upward to the beginning of its exit from the water) and (vi) recovery (time corresponding to the point of water release to water re-entry of the arm).

The duration of the propulsive phases of front crawl and backstroke was the sum of the pull and the push phases. The duration of the non-propulsive phases was obtained by the sum of the catch and the recovery phases. In front crawl (A panel left). Inverse relationship between IdC and velocity in backstroke (B panel right).

RESULTS

The individual and mean ± SD values for all stroke phases, the propulsive and non-propulsive phases, the IdC (all expressed in percentage of a total cycle duration) and corresponding swimming velocity are presented in tables 1 and 2 for front crawl and backstroke, respectively. All swimmers showed negative IdCs. All used a catch-up coordination mode in both swimming strokes.

Table 1. Individual and mean ± SD values for the arm stroke phases, propulsive and non-propulsive phases, IdC and velocity in all out front crawl swims in persons with Down syndrome.

| Subject | Catch (%) | Pull (%) | Push (%) | Recovery (%) | Propulsive (%) | Non-propulsive (%) | IdC (%) | V (m/s)
|---------|-----------|----------|----------|--------------|---------------|-------------------|---------|-------
| 1       | 10.4      | 24.6     | 24.1     | 35.0         | 65.0          | 13.6              | -11.6   | 0.9   |
| 2       | 17.6      | 28.9     | 28.0     | 46.5         | 53.5          | -2.4              | -9.2    | 0.7   |
| 3       | 13.3      | 22.2     | 32.2     | 35.5         | 64.5          | -17.7             | -17.7   | 0.9   |
| 4       | 7.5       | 24.5     | 57.0     | 36.5         | 63.5          | -13.9             | -13.9   | 1.0   |
| 5       | 14.1      | 27.5     | 29.5     | 41.6         | 58.4          | -5.6              | -5.6    | 0.9   |
| 6       | 17.5      | 21.6     | 30.8     | 39.1         | 60.9          | -12.5             | -12.5   | 1.2   |
| Mean    | 14.2      | 24.9     | 33.6     | 39.0         | 61.0          | -13.3             | -13.3   | 0.9   |
| ±SD     | 11.3      | 2.9      | 11.8     | 8.4          | 4.4           | 5.2               | 5.2     | 0.2   |

Table 2. Individual and mean ± SD values for the arm phases, propulsive and non-propulsive phases, IdC and velocity in all out backstroke swims in persons with Down syndrome.

In the front crawl, a significant relationship was found between the IdC and the relative duration of the push phase (r = 0.88), as well as with the propulsive phase (r = 0.92), as observed in Figure 1A. An inverse relationship was found between the IdC and the non-propulsive phase (r = -0.92). No significant relationships were observed between the IdC and the catch phase (r = -0.06), the pull phase (r = 0.52), the recovery phase (r = -0.30) and swimming velocity (r = -0.48).

![Figure 1](image)

Figure 1. Relationship between IdC and the push and propulsive phases in front crawl (A panel left). Inverse relationship between IdC and velocity in backstroke (B panel right).

In backstroke, there was a significant inverse relationship between IdC and velocity (r = -0.89), as observed in Figure 1 (B). No significant correlations were observed between IdC and all the other parameters: catch phase (r = 0.10), pull phase (r = 0.37), push phase (r = 0.57), hand lag time phase (r = 0.26), clearing phase (r = 0.02), recovery phase (r = -0.56), propulsive phase (r = 0.73) and non-propulsive phase (r = -0.73).

DISCUSSION

Swimming technique is one of the major factors influencing swimming performance. To better characterize the technique of swimmers with DS, arm coordination was assessed in the alternating strokes front crawl and backstroke using the IdC. In addition the relative duration of each arm stroke phase, together with relative duration of propulsive and non-propulsive phases were determined. To our knowledge, no work has been done on arm coordination in swimmers with DS.

In both strokes when performed at high intensities, the catch-up
arm coordination was observed exclusively. For the front crawl, the use of a catch-up coordination mode is usually considered by coaches and instructors as a technical fault (Seifert and Chollet, 2008) and is observed in less skilled swimmers (Seifert et al., 2008). This coordination mode does seem to be efficient at slow paces, as it favors a glide phase following propulsive actions (Seifert et al., 2004b). These authors found that when the velocity increases above a critical value, a transition from catch-up to superposition mode is seen. In the present study swimmers performed a maximal intensity protocol and the use of catch-up coordination appears to be indicative of a less proficient technique. Interestingly, Seifert et al. (2004a) showed that women have more negative IdC values than men due to their higher fat mass values, different fat mass distribution, lower arm strength, and as a result greater difficulty in overcoming forward resistance. These are also characteristics of individuals with DS (Aleixo et al., 2009). Other physical characteristics, such as a smaller propulsive surface, also found in swimmers with loco-motor disabili-ties, can also influence their inter-arm coordination (Satkunskiene et al., 2005). The direct relationship found between the IdC and the phase of the arm and propulsive phases, also described in the literature on able bodied swimmers (Figueiredo et al., in press) emphasizes the importance of the propulsive phase duration in an arm stroke.

In backstroke, the catch-up coordination mode is the only pattern of arm coordination used, with IdC values varying between -25% and -5% (Seifert and Chollet, 2008). This fact seems to be due to the limited shoulder range of movement and to the alternating body-roll (Chollet et al., 2008), which impose a particular arm coordination and an additional stroke phase - clearing phase (Lerda and Cardelli, 2003). This clearing phase prevents continuity between the propulsive phases of the two arms. This is only found when a three-peak stroke pattern is used, creating some propulsion in the beginning of the upsweep (Maglischo, 2003). This three-peak stroke pattern was not seen in the present study. On the contrary, a hand lag time phase was found in all swimmers in accordance with Chollet et al. (2006) and Chollet et al. (2008). These authors pointed out that this arm phase can affect the arm coordination in backstroke, since it leads to propulsive discontinuity, explaining why elite swimmers limit their hand lag time to approximately 2% of the stroke cycle duration (a much lower value than found in the present study). The very existence of this phase is, however, controversial because some studies (e.g. Lerda and Cardelli, 2003; Lerda et al., 2005) did not report this.

Although the participants in this study are international level Down Syndrome swimmers, their arm coordination does not correspond to the values of typical elite swimmers without DS, suggesting the presence of technical faults or physical shortcomings (e.g. higher hand lag time). The IdC values of the present swimmers are closer to those found by Cardelli (2003) for less expert swimmers (-11.3%) compared to more expert backstrokers (-9.7%). The inverse correlation between IdC and velocity was also found by Chollet et al. (2008), corroborating the findings elsewhere of higher (less negative) IdC values at higher swimming velocities.

CONCLUSION

International level swimmers with DS presented a catch-up arm coordination mode in front crawl, which may be associated with less proficient arm coordination. Trained swimmers usually change from catch-up to superposition with increasing velocities. The catch-up coordination mode was also found in all swimmers for the backstroke. This is in concordance with the literature on less skilled swimmers and for skilled swimmers at low velocities. The high values of hand lag time contributed to this.

It can also be pointed out that this instrument can be very helpful to coaches in better understanding underwater stroke phases. These findings also emphasize the importance of augmenting the propulsive phases of the arms and, with this, diminishing the lag time of the swimmers. Technical mistakes can also be detected through the study of the arm coordination.

REFERENCES


Identifying Determinant Movement Sequences in Monofin Swimming Technique

Rejman, M. & Staszkiewicz, A.

University School of Physical Education, Wroclaw, Poland

The aim of this study is to identify errors in leg and monofin movement structure, which lower the effectiveness of swimming. The movement cycles of six swimmers were filmed underwater in a progressive trial (900 m at increasing speeds). Results due to kinematical analysis were obtained as temporal data for: angle of foot bending in relation to the shank, proximal end of the monofin in relation to the foot and for angle of attack of the distal part and entire fin surface. The parameters were selected according to an existing functional model of monofin swimming. Hence, the identification of determinant movement sequences and technical key elements in monofin swimming and their quantification, make sense in order to anticipate and eliminate errors.

Key words: swimming, monofin, determinant movement sequence, technique errors

INTRODUCTION

The surface area of a monofin is about 20 times larger than human feet, and it is a more relevant source of propulsion. Monofin swimming for learning, leisure or water rescue requires basic technical ability. At elite sporting level, a perfect technique is required, as the monofin does not “forgive errors”. An error may objectively be defined as a performance of movement not in accordance with a given pattern. From motor point of view, it may be a movement not in accordance with the original intention (Brehmer and Sperle, 1984). A determinant movement sequence is literally the general execution of movement activity which is determined to be “correct” by objective parameters. The ability to verbally name a movement precisely allows the combining of cognizant execution of action, with the perception of what this action should be, supporting the intellectual process of teaching and perfecting technique (Richard et al., 2005).

Explicit conditions generating monofin propulsion form the basis of several biomechanical analyses of technique, which develop a description of the existing processes generating propulsion (e.g. Colman et al., 1999), formulate quality criteria for swimming technique (e.g. Shuping et al., 2002; Rejman, 2006) and create a search through modeling (e.g. Wu 1971). The remaining analysis is set aside for the aspects of biomechanical application – useful in training procedures (e.g. Rejman and Ochmann, 2009; Persyn and Colman, 1997). Therefore, the aim of this study was to identify errors in leg and monofin movement structure, which lower the effectiveness of swimming. The research assignments formulated within the context of the use a monofin for maximum swimming speed are: (1) the identification of errors in the leg and monofin movement in order to describe their structure and scale; (2) the identification of determinant movement sequences and key technical elements of leg and monofin movement in terms of potential errors, with an aim towards their anticipation and elimination; (3) the identification of the relation between monofin swimming speed and the structure and scale of errors, with an aim towards the isolation of determinant movement sequences within the measure of quality of monofin swimming technique.

METHODS

Six representatives of the Polish Monofin Swimming Team (homogenous in terms of age, somatic parameters and championship level of technique) took part in the research. They conducted a progressive test (swimming 900 m at increasing speeds). To register parameters describing the leg and fin movements, the swimmers were filmed underwater. Identification marks were placed on the axes of the hip, knee and ankle joints. The monofin was also marked (at the tail – where the plate is joined to the feet, at the middle and at the edge of the fin). The marks served to divided the fin into proximal (between tail and middle) and distal (between middle and edge) parts, as well as to monitor the entire surface of the fin. A random cycle (each 100m) from each swimmer was chosen. SIMI System (SIMI Reality Motion Systems GmbH, Germany) was used for kinematic analysis. The results were obtained in the form of temporal data for the angles of bend at the foot in relation to the shank (KAT), the proximal part in relation to the foot (ATM), the angle of attack of the distal part (HME) and the entire surface of the fin (HME). The existing model exactly these parameters were found to create maximum swimming speed when they are optimized (Rejman & Ochmann, 2009). Friedman’s test and Kendall’s coefficient, useful in analysis of small groups were applied to confirm the existence of the similarities in the data studied.

RESULTS

Based on information related to the scale and structure of errors committed by swimmers (Figure 2, Table 1) the following generalizations were formulated: (1) the fastest swimmer made fewer errors, in terms of the parameters examined, than the slowest; (2) movement errors deducted from the model were mainly related to angular displacement, with the exception of the ankle joint angle during upbeat, performed by the slowest swimmer; (3) based on the average values of sum of errors it...
may be assumed that the most difficult element of monofin swimming is the proper range of motion in the ankle joints; (4) an analysis of the differences between value of errors performed, suggests the parameter most differentiating the fastest from the slowest swimmer, is the angle of bend of the feet in relation to the shanks (19.5%). The angle of attack of distal part of the fin (11.5%) placed second in the ranking mentioned. The differences between values of errors in terms of the angle of bend in the proximal part of the fin (7.3%) and angle of attack of the entire fin (6.8%) was the lowest, even when most similar. (5) The errors estimated high correlated to swimming intracycle velocity.

Figure 2. Graph illustrating scope of errors (ER) in angle of the foot flexion in relation to shank (KAT) in time function. At left are sequences of movement illustrating the range of errors showed in the graph. Sum of errors by fastest and slowest swimmers compared to average value calculated for all swimmers.

Table 1. Pearson’s correlation coefficients between value of error in cycle made by all subjects on 100-m sections, and average velocity (ranked by average velocity). (KAT) – angle of bend in foot at ankle joint; (ATM) – angle of bend in tail of monofin; (HME) – angle of attack of distal part of fin, (HTE) – angle of attack of entire surface of fin.

The following determinant movement sequences were estimated. The end of the downbeat movement, where the knee joints straighten, the legs are straight, the feet are in their lowest downbeat position, the tail is at maximum bent at the maximum angle of attack of the entire surface of the fin (Table 2(1)). The change ankle joint angle and the angle between proximal part of the fin and the feet is during the downbeat – beginning of the phase where the legs are maximally flexed and the segments of the fin are more or less parallel (Table 2(3)) and finally, during upbeat – the last part of upward movement, with legs straightened, just before flexing at the knees, at the maximum bend of the tail of the fin (Table 2(2)). The determinant movement sequence referring to the change of angle of the distal part of the fin and its entire surface is in the downbeat - the second part of legs straightening at the knees, where the shanks are more or less parallel to the direction of swimming and the monofin is more or less straight in the maximum angle of attack (Table 2(4)). During upbeat – the second part of the lifted legs straightened with the knees up, until the legs are placed more or less parallel to direction of swimming and the monofin is at maximum bend in the middle (Table 3(5)). The key elements in the movement structure of legs and monofin were also described (Table 1).

Table 2. The determinant sequence of leg movements and monofin (1,2,3,4,5) arranged with the key elements in the structure of monofin and leg movements (A,B,C,D), related to occurrence of errors.

DISCUSSION

 Errors in propulsive movement structure and their impact on swimming speed, are relevant to the principle of equilibrium of momentum due to the interaction between the water and swimmer. Without errors momentum transfer between the subsequent leg segments and the monofin, is most effective (Rejman, 2006). Therefore, the determinant sequence initiated in the category of quality of momentum transfer, occurs between subsequent elements of the feet - parts of the monofin’s chain.

The swimmers tested in this study show a low level of control over feet movement while executing propulsion actions. The angle of bend of the feet in relation to the shanks is the most difficult element of the movement structure (Figure 2). Additionally, changing this angle in the function of time and layout of errors, demonstrates the least mutual similarity among the parameters tested. The dominant role of foot movement in generating propulsion is revealed in results gained from the construction of a neural network (Rejman and Ochmann, 2009) as well as research on factors supporting maintenance of consistent high infracycle monofin swimming velocity (Rejman, 2006). The aim of these suggestions was to avoid placing the fin parallel to the direction of swimming. The results confirmed that, the feet as an active (under total control of the swimmer) element in the biomechanical chain are the final link of torque transfer from the legs to the surface of the fin (Rejman, 2006). Hence, correct movement in this element of the sequence structure of propulsion seems to be important. Cognitive control of foot movement allows for self-correction of swimming technique. The tendency toward excessive plantar flexion of the feet (observed generally, not only in the research group) thus seems unjustified from the point of view of swimming efficiency.

An analysis of the value of sum of errors made by swimmers indicated similarities between angle of bend in the tail of the monofin (ATM) and angle of attack of the distal part of the fin (HME) (Figure 2). Similarities were also noted when comparing the values of difference between angle of bend in the tail of the monofin (ATM) and angle of attack of the entire surface of the fin (HTE) This may indicate that the bending of the tail of the fin, influences the change in shape of the monofin’s surface. It is accepted that the tail is the place where transfer of torque, generated by the legs, to the surface of the fin is performed (Rejman, 2006). With this in mind, the tail is the key element in analyzing the biomechanical chain, dividing it into parts consisting of leg segments and monofin segments. Supporting this thesis are results showing that the optimal plantar flexion during downbeat, limits the bend of the tail, as a result optimizing the angle of attack of the proximal part of the fin. Optimal dorsal flexion of the fins during upbeat causes greater tail bending and consequently, the angle of attack of the distal part and entire fin, achieves optimum range in both phases of the cycle (Rejman and Ochmann, 2009). These suggestions are confirmed in the present work. Greater optimization of tail bend, within limits established in the
functional model (forming an isolated sequence) leads to the appearance of reserves in swimming technique, supporting the achievement of maximum swimming speed (Rejman and Ochmann, 2009).

Due to optimal mutual actions of the feet, tail and the parts of the fin with speed, the formation of vortices occurs. These become an additional source of propulsion. Stable vortex circulation creates additional momentum due to velocity changes of water mass, produced by the rotational velocity of the vortex (Colman et al., 1999). It seems that the efficient transfer of torque over the surface of the fin, no matter if directly from leg movements, is subordinated to the hydrodynamic conditions of water flow over the surface of the fin. In this aspect, the dynamic transfer system, displayed as changes to the angle of attack of the monofin, changes the structure of water flow over its surface, and appears to be a key to effective swimming. The results obtained correspond to the analysis of particular components of force generated on the surface of the fin, with respect to the change in intracycle velocity (Colman et al., 1999; Rejman et al., 2006) (Table 2 - B, D) – in extreme upper and lower feet position, where the legs are straight at the ankle joint, the monofin bends at the tail, and its midsection is placed parallel to the direction of swimming. The research cited indicates that the main source of propulsion in this part of the cycle are drag and lift forces as well as accompanying components due to vortex induced momentum and the flexion of the fin. These same authors believe that maintaining the velocity cited, plays a main role in placing the distal part of the fin parallel to the direction of swimming (Table 2 = (A, C) – maximum bend of the distal part and entire surface of the fin, during change of direction of edge movement). In the sequences described, the energy essential to swimmer propulsion emanates from both additional mass slides away from the edge and acceleration reaction.

The diagnostic value of the parameters analyzed was confirmed in an earlier constructed model of functional swimming and monofin technique (Rejman and Ochmann, 2009). It was also confirmed that, the greater the influence of the parameter on swimming speed, the more difficult the performance of proper movement in relation to this parameter. The errors indicated concern the fragments, which registered the highest intracycle velocity (confirmed by correlation coefficients (Table 1)) suggesting that, the achievement of maximum intracycle speed, is a consequence of proper execution of the determinant sequence of movement. No difference was demonstrated in terms of the change in angular foot movement, in subjectively interpreted conditions, ensuing from fatigue during swimming of subsequent distances of the trial. Therefore, there is a basis for the objective evaluation of the reliability of the errors, which occurred. The procedures outlining deterministic sequences, on the basis of errors analyzed, create an empirical foundation for treating this sequence as a tool for evaluating monofin swimming technique (Table 2).

CONCLUSION

Precise control of foot movement, allows for achieving a dynamic system transferring torque, as a basis of propulsion, which creates momentum, bending the tail of the fin during transfer, thus changing the shape of the fin and the structure of water flow over its surface. This same proper sequence of propulsive movement creates conditions for using the surface of the monofin to achieve maximum speeds. Therefore, it is justified to assign key elements to monofin swimming technique, for the quantification of its quality, and for the anticipation and elimination of errors during the technical training.

REFERENCES


Evaluation of the Gliding Capacity of a Swimmer

Roig, A.

GIRSANE Research Group from Olympic Training Centre, Barcelona, Spain

Reducing resistance is probably the fastest way to improve performance and the most efficient to reduce energetic cost. Therefore, the aim of this study was twofold: (i) to give advice to coaches to re-orient their training sessions towards reduction of resistance forces and suggest exercises for its improvement and, (ii) to develop and apply a new test for the evaluation of gliding. The proposed gliding test evaluated the maximum speed reached by the swimmer after push-off and the passive hydrodynamic resistance when gliding through the water. A well-balanced solution between accuracy, validity and applicability for the evaluation of underwater glide was found.

Key words: Gliding coefficient, hydrodynamic position, resistance force, starts, turns

INTRODUCTION

The capacity to move its own body through the water with the lowest resistance should be included among the most important qualities of a swimmer. Advancing through a liquid, the swimmer evacuates water and occupies its place, causing the hydrodynamic resistance that acts in the same swimming direction but in the opposite sense.

The underwater phase represents an important part of the entire race time (Chow, 1984). This is even more true in a 25m-pool race, where the number of turns is doubled.

During the phases of pure gliding, in starts or turns, the swimmer tries to maintain the highest velocity of all race obtained after push-off (highest peak of speed in figure 1).

The higher the speed of the swimmer, the higher will be the resistance to overcome. Therefore, in those phases of the race, where velocity is increased (start and turns), the swimmer will have to pay much more attention on reducing resistance forces. An accurate underwater technique combines the capacity to self-propel in the water and to reduce braking forces to the minimum for a beneficial use of the generated propulsion. Both qualities coexist when a swimmer travels in the water and should be optimised to obtain the highest velocity.

Many factors may determine the gliding capacity of a body inside the water. One of them, the fluid density (water is about 1000 times more dense than air) is not controllable by the swimmer and is equal for all participants. Others, as frontal area, skin and swimsuit friction, or body shape, can be modified and have to be improved in training sessions. A slender and aligned body in the moving direction will produce a lower resistance. New swimsuits seem to slightly alter the parameters that increase the swimmers gliding, modifying buoyancy and alignment (slender the body shape and avoid feet falling) and reducing friction by means of removing seams and using new textile that minimizes turbulence generation.

Many authors like Clarys (1979), Maiello et al. (1998) and Lyttle et al. (2000) have studied the effect of depth of glide onto resistance forces, concluding with different opinions, some of them even opposed.

Diminishing resistance is probably the fastest way to improve performance and the most efficient way to reduce energetic cost. It is for this reason that we pursued a double goal: To give advise to coaches to re-orient their training sessions towards the reduction of resistance forces by suggesting exercises for its improvement and to develop and apply a new test for the evaluation of gliding.

METHODS

The proposed gliding test is an adaptation of the one developed by Klauck et al. (1976) and evaluates simultaneously, the maximum speed reached by the swimmer after push-off from the wall and the passive hydrodynamic resistance when gliding through the water. Gliding test is being applied to swimmers training at the Olympic Training Centre in Barcelona, belonging to a wide variety of performance levels, including Olympic, World and European Championships and Paralympics' swimmers.

Three underwater cameras are placed at the pool’s sidewall at a distance of 2m between them (Figure 2). The first camera distance from the wall varies and is equivalent to the distance reached by the swimmer’s head with his feet extended. For example, if first camera was placed at a distance of 1.9 m, the following ones were placed at 3.9 m and 5.9 m. A 4th travelling “dolly” camera followed the swimmer along the pool’s sidewall.

Figure 1. Velocity graph of a breaststroker during start.

Figure 2. Camera and buoy placement for the evaluation of resistance factor.

The swimmer pushed off from the wall and adopted the most hydrodynamic position until his body stopped. Two trials were recorded for each chosen body orientation: ventral (facing down), dorsal for backstrokers (facing up) and lateral position. In addition, the swimmer performed a turn, starting 10 meters before the wall and glide, as done before, to maximum distance. This variant detects if push-off or glide were affected by previous swim or flip.

Image review of the exercise permitted the detection of possible mistakes on technique. A list of indicators were pre-defined for the analysis of power application against the wall and resistance reduction while gliding: feet gap, support surface of feet against the wall, knee flexion, head within arms, shoulder rising to lengthen the body, overlapping of hands, extension of elbows, non-arched trunk and alignment of hands, elbows, shoulders, hips, knees, feet and toes in the trajectory line of glide. The video images were also used for the calculation of time of head passing in front of each camera and the time spent to cover the distance of 2 meters between each pair.

Signals from a velocity meter were recorded, also. This device, attached to the swimmer’s hip by a thin belt, registered the instantaneous speed during the exercise. The following parameters were obtained from values of the velocity graph:

Figure 3. Gliding test emissions.
- maximum speed after push-off (VMax) as a result of applying the maximum power against the pool's wall.
- distance covered after gliding time following push-off. SL = V AVG * dT
- gliding resistance coefficient. Gc = 20 / dT * (1 / VFinal - 1 / VInitial), where:
  - dT is Gliding time, V_initial is Maximum velocity obtained after push-off and V_Final is Instant velocity at the end of dT
  - Gc includes in a single parameter, frontal area (A) and friction and shape coefficient (C_d) and derives from the following formula that explains the resistance force of a body travelling through a gas or liquid:

\[ F_d = \frac{1}{2} \rho v^2 C_d A \]

where:
- \( \rho \) = Density of fluid (water)
- \( v \) = Relative velocity of the swimmer with respect to water. During turns, water will be moving at a certain velocity and at the same direction but opposite sense to the swimmer, because of his body's approach to the wall before turn.
- \( C_d \) = Resistance coefficient. Describes how slender the body of the swimmer is. It is mainly explained by the resistance generated by friction of swimsuit and skin against the water and swimmer's shape.
- \( A \) = Projected frontal area of the swimmer's body.

RESULTS

When comparing Klauck's Resistance Factor \( R_f \) and proposed Gliding Coefficient \( G_c \), the observed \( F (154.64) \) was higher than the Critical \( F (4.05) \), meaning that both coefficients evaluated loss of speed and are linearly related by the equation \( R_f = 0.0403 \times G_c + 0.089 \) for the group of 48 swimmers (Determination Coefficient \( R^2 = 0.771 \), Standard Error of Estimation \( SEE = 0.0213 \) and Critical \( T = 2.3172 \)). Therefore, the 95% confidence interval of estimated values of \( R_f \) from \( G_c \) is defined by equation \( R_f = 0.0403 \times G_c + 0.089 \pm 2.3172 \times 0.0213 \).

Personal reports (exemplified by Figures 3 & 4) for each swimmer contained a description of errors in technique observed in video images and the related values from velocity curve: elapsed time to cover both 2 m distances, resistance factor (\( R_f \)), maximum initial velocity, glided distance after period of time and gliding coefficient (\( G_c \)).

Range of values of the gliding coefficients obtained from tested swimmers has been wide, because of gender, age, size, shape and expertise differences. A high push-off power will initially enable the swimmer to travel faster and further, but will also be the cause of a higher resistance force to overcome (resistance force \( F_d \) increases proportionally to the square of velocity as shown previously in formula). Once moving, two factors will be determinant: Body shape and size, and body position and alignment (technique).

As shown in figure 5, the best gliders obtained the lowest values of \( G_c \), because of either a higher initial velocity (2.87 m/s of upper curve vs. 2.42 m/s of lower curve) or a small lost of speed (top curve vs. middle curve). Lower initial velocities and / or higher decelerations will lead to a higher value of \( G_c \) (7.01 of lower curve vs. 3.52 of upper curve) of a bad glider. Higher-level swimmers average better values of \( G_c \) than the less experienced, even though improvements on swimmers with lower training experience have been very obvious so far.

**DISCUSSION**

Technique learning is a complex process. Every swimmer has its own characteristics and tries to reproduce technical patterns to reach the highest performance. Having a better conscience of what is doing, the proposed modifications and its results, will lead to an improvement of his technique. Videography offers a visual feedback of what the swimmer is doing. The velocity meter evaluates the increments of speed on propulsive actions and decelerations caused by hydrodynamic resistance. Graphing velocities over video images will allow the swimmer to establish a direct relation between “what he/she feels” (sensations) with “what he/she does” (video images, execution) and “the result of what he/she does” (speed, deceleration, performance).
Both Resistance Factor (RF) and Gliding Coefficient (Gc) measure loss of speed, but they present their own advantages. Klauck’s gliding test methodology has the advantage of not having a cable attached to the swimmer’s hip and the possibility to compare with trials preceded of a turn. The proposed methodology uses of a velocity meter and offers the possibility to calculate parameters like maximum speed, glided distance, instantaneous velocity and gliding coefficient Gc within any chosen period of gliding time. This peculiarity has been of great help to determine the precise instant to quit gliding and to start underwater kicking on starts and turns.

CONCLUSION

Starts and turns can be cut-off and analysed by parts. As a result, experts are able to better define lacks on technique and establish priorities in training sessions to reach the best performance. A well-balanced solution between accuracy, validity and applicability for the evaluation of underwater glide has been found. Coaches have designed and included specific exercises for the training of the glide, starts and turns in every day practice and sport science have increased their presence in the everyday work of swimmers. When applied on young swimmers, the gliding test seems to be of great use for talent detection.

REFERENCES


ACKNOWLEDGEMENTS

I would like to thank coaches from Spanish and Catalan Swimming Federation and Paralympic Committee, as well as my sport’s sciences colleagues from GIRSANE (Research Group from Olympic Training Centre in Barcelona, Spain).

Effects of a Blueseventy™ Bodysuit on Spatial-temporal and Coordinative Parameters During an All-out 50-m Front Crawl


Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil

The aim of this study was to establish the effects of using a shoulder to ankle bodysuit (Blueseventy™) on spatial-temporal and coordinative parameters during an all-out 50m front crawl swim. Six subjects (16.6 ± 2.0 yrs) performed two all-out 50m trials (with and without bodysuit). The arm stroke parameters and index of coordination were determined by videography. A repeated measures ANOVA was performed, with main effects verified using LSD post-hoc for α < 5 %. Using the bodysuit, swimming speed and stroke length were higher. The duration of the entry and catch phase and non-propulsive phase were shorter in the second 25 m split. No statistical differences in index of coordination were found. Wearing the bodysuit significantly improves the swimming performance, mostly on the second half of the test.

Keywords: High-tech bodysuits, swimsuits, coordination, front crawl

INTRODUCTION

The implementation of new technology in order to enhance sports performance has resulted in a range of new equipment that can be used during training and competition. Most prominent among these advancements has been the development of highly technical bodysuits purported to improve swimming performance.

The original purpose of these swimsuits was to decrease drag by mimicking sharkskin. The latest bodysuits, however, also appear to improve buoyancy and compress body parts (Benjanuvatra et al., 2009). The body suits have been further developed through the use of particular fabric and by the manner in which the suits are sewn. Indeed, the most advanced bodysuits have no sewn parts at all.

The evolution of high technology bodysuits is almost certainly a major factor in the recent spate of new world records in swimming events. As a result, questions have been raised concerning the fabric composition and availability as well as ethical and legal issues linked to using these suits in competitions. FINA subsequently banned the bodysuits in indoor competitions from January 2010. But the suits are free to be utilized in open water and triathlon events. Furthermore, there does not exist enough research on the effects of using bodysuits on swimming performance.

Spatial-temporal parameters, as well as the index of coordination, proposed by Chollet et al. (2000), appear to be dependent on restrictions of the organism, the environment and the task (Seifert et al., 2007). Thus, the purpose of this study was to establish the effects of using a bodysuit (Blueseventy™) on spatial-temporal and coordinative parameters during an all-out 50m front crawl performance. Considering the improvement in performance (Benjanuvatra et al., 2009), increased stroke length and swimming velocity and a greater continuity in propulsion actions (index of coordination near zero) were expected wearing the bodysuit.

METHODS

Subjects: Six subjects, each competitive at Brazilian age group national level, took part in this investigation (age: 16.6 ± 2.0 yrs; body mass: 67.8 ± 5.9 kg). All participants signed a consent form prior to which the aims, risks and procedures associated with this trial had been fully explained. The sample size was limited by the Blueseventy™ bodysuits availability.

Trials: The subjects performed two all-out 50m trials in a 25 indoor pool, starting in the pool. One trial was performed with an ordinary
suit (short made by Lycra) and one using a Blueseventy™ bodysuit that covered from the shoulders to the ankles. The order of the trials was randomized and the subjects rested for 20 min between the trials. The subjects used their own bodysuits during the trials.

Video sampling and analysis: Two synchronized sub-aquatic video cameras (SANYO VPC-WH1), operating at 30 Hz, were used to acquire images in the sagittal plane of the swimmers. The cameras were positioned on the lateral sides of the pool and were carried manually using chariots on rails. To determine the stroke phases, two experienced researchers made a frame-by-frame analysis as reported before by Chollet et al. (2000) using the software VirtualDub v1.8.7. A third independent video camera operating at 25 Hz (JVC, GR-DVL9800) was positioned 4 m above the water surface in the middle of the pool deck to measure race parameters. This camera allowed us to quantify swimming speed and stroke rate, from which stroke length was calculated. The analysis of the images was performed with the software Dgme v1.0.

Index of coordination and arm stroke phases: Index of coordination (IdC) was taken to represent arm coordination, as proposed by Chollet et al. (2000). The index of coordination was expressed as a percentage of the duration of one arm stroke and represents the time between the end of propulsive action of one arm and the beginning of propulsion with the other arm, considering the mean of both the right and left arms. Therefore it is possible to quantify a catch-up (IdC < 0%), an opposition (IdC > 0%) or a superposition coordination mode (IdC = 0%).

The duration of the stroke phases were expressed in absolute values (s), divided into four phases: (1) entry and catch: from the entry of the hand into the water to the moment prior to the beginning of its backwards movement relative to the body, (2) the pull: from the beginning of hand’s backwards movement until the moment where the hand is in a plane vertical to the shoulder, (3) the push: from the point where the hand is below the shoulder until its release from the water and (4) the recovery: from the point of water release to the hand re-entry into the water. The pull and push phases were considered the propulsive ones and the entry and catch and the recovery were considered the non-propulsive phases of the stroke.

Mean, standard error and deviation, normality and sphericity were calculated and verified for all the analyzed variables. To verify the effects of the bodysuit and the split of the trial (first or second 25 m split) on selected variables, a repeated measures ANOVA was performed (mixed model 2 x 2 – two suits and two 25 m splits), with main effects verified using LSD post-hoc. For the stroke phases where there was an interaction between the split and suit condition, the Student t test for paired data was used, allowing for comparison of each of the splits on the two suit conditions.

DISCUSSION

The purpose of this study was to analyze the effects of using a high performance swimming suit (Blueseventy™) that covers from the shoulders to the ankles on spatial-temporal and coordinative parameters of front crawl swimming during an all-out 50 m trial.

Using the bodysuit enabled the subjects to swim on average 4.7 ± 2.2% faster, which is more than found in a study by Chatard and Wilson (2008), who reported a 3.2 ± 2.4% increase in swimming speed using the FastSkin™ body suit, that also covers from the shoulder to
the ankles during 25 to 800 m all-out trials. It is likely that the larger increase in speed found in our study is due to the fabric composition of the suits from Blueseventy™, made of 75% nylon and 25% PU-CR (polyurethane that improves buoyancy), in contrary to the polyester and lycra composition of the FastSkin™.

Parsons and Day (1986) and Cordain and Kopriva (1991) analyzed the effects of wetsuits, allowed in triathlon competitions and made of low-density material, which is similar to the bodysuits analyzed in our study. The authors suggested that the performance enhancement was directly related to the improved buoyancy offered by the suit. According to Benjanuvatra et al. (2002), improved buoyancy allows a smaller energetic cost to sustain an optimal body position, and therefore greater force can be applied on generating propulsion.

In the present study, the increase in speed was due to an increase in stroke length, since there was no difference in the stroke rate when using the bodysuit. Roberts et al. (2003) found similar results when comparing front crawl swimming using the Speedo Fastskin™ to ordinary suits. These authors, however, analyzed sub-maximal swimming intensities. Chatard and Wilson (2008) found a significant decrease of the energetic cost associated with an increase of the stroke length when using the Fastskin™ body suit, which means improved swimming economy.

Our subjects showed a shorter duration of the entry and catch phase during the second split of the trial when using the bodysuits. Parsons et al. (2003) found similar results when comparing front crawl swimming using the Speedo Fastskin™ to ordinary suits. These authors, however, analyzed sub-maximal swimming intensities. Chatard and Wilson (2008) found a significant decrease of the energetic cost associated with an increase of the stroke length when using the Fastskin™ body suit, which means improved swimming economy.

Analyzing the subjects individually, five subjects showed a similar index of coordination on both suit situations and one subject showed a greater continuity between the propulsive actions during the first 25 m split. During the second split four out of the six subjects showed a greater continuity of the propulsive phases using the suit and the other two did not change their index of coordination values. This suggests that the suit may have a greater influence on technique during the final portion of the race.

Since the suit did not interfere with the duration of the propulsive phase of the stroke, the greater stroke length is probably as a result of more effective force application during the phase probably due to a decrease in drag. The propulsive effectiveness is dependent on the combination of a high displacement speed of the hand and its adequate trajectory during the propulsive phase, generating higher peak forces (Toussaint & Beek, 1992).

It was not possible to evaluate the body compression caused by the suit, if any, and this is a limitation of this study. However, the subjects reported difficulties to put on the suits, taking a long time dress them properly. Kainuma (2009) suggests that the compression of the LZR Racer™ from Speedo, can modify the physiological systems by an alternative mechanism, where the compression would affect the blood circulation, forcing the use of anaerobic-glycolitic pathways. This would in turn enable an instantaneous increment in force generation, which could have some influence on short distance, more high-speed races.

Even though we randomized the tests order and tried to verbally stimulate the athletes the same way on both trials, a possible placebo effect could not be controlled for.

### CONCLUSION

Wearing a full bodysuit, covering from the shoulders to the ankles, from Blueseventy™, significantly improves the swimming speed during an all-out 50 m front crawl swimming trial, mostly on the second half of the test. When wearing the suits, the subjects showed a greater stroke length during both 25 m splits and shorter duration of the non-propulsive phase of the arm stroke during the second half of the test.

### REFERENCES


### ACKNOWLEDGEMENTS

The authors want to express their gratitude to the athletes and coaches from Grêmio Náutico União, for the contribution in this study, and to Aquatic Sports Research group for their cooperation.
Fatigue Analysis of 100 Meters All-Out Front Crawl Using Surface EMG

Stirn, I.¹, Jarm, T.², Kapus, V.³, Strojnik, V.¹

¹University of Ljubljana, Faculty of sports, Ljubljana, Slovenia
²University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia

INTRODUCTION

The use of surface electromyography (EMG) enables monitoring fatigue process in different muscles simultaneously (DeLuca 1984). As fatigue progresses the amplitude of the EMG signal increases due to synchronization and recruitment of motor units (Merletti et al. 1991). During swimming this was shown by analyzing integrated EMG (iEMG). Wakayoshi et al. (1994) estimated the iEMG of some arm muscles at different swimming velocities, while Rouard et al. (1997) monitored iEMG during a 4 x 100 meters front crawl at 85% of swimmer’s best performance.

For the evaluation of muscle fatigue the EMG signal is usually analyzed in the frequency domain. The mean (MNF) or median (MDF) frequency of the power spectrum is shown to shift to lower frequencies during an increasing fatigue (DeLuca, 1984). Most of the decrease of the MNF and MDF is attributed to the diminished muscular fiber conduction speed (MFCV) as a consequence of local metabolic changes in working muscle.

Aujouannet et al. (2006) evaluated muscle fatigue by comparing MNF of the EMG measured during isometric contraction of arm flexors before and after swimming. They found that MNF of the EMG power spectrum for the biceps brachii and triceps brachii muscles decreased after a 4 x 50 meters front crawl at a maximum intensity with respect to the values obtained before the swim. Caty et al. (2006) examined MNF decrease in two forearm muscles during swimming. A decrease of instantaneous MNF in the extensor carpi ulnaris and flexor carpi ulnaris muscles was observed (11.41% and 8.55% respectively) during the 4 x 50 meters front crawl swimming and was attributed to the fatigue of the muscles due to their wrist stabilization role during swimming.

The aim of the study was to estimate fatigue of selected propulsive muscles by analyzing EMG signals during 100 meters all-out front crawl in amplitude and frequency domain. In order to better understand and interpret results some kinematic (stroke length, stroke speed, stroke rate) and physiological (lactate concentration) data were obtained as well.

METHODS

Eleven male experienced competitive swimmers (age 22.0 ± 2.9 years), involved in swimming for 13.6 ± 3.1 years with an average personal best result in 100 m front crawl 53.05 ± 1.72 s, participated in the study. The measurements were performed in a 25-meter indoor swimming pool. After putting on all the equipment and the warm-up the subjects performed a 100 meter all-out front crawl swim. Because of the measurement equipment they started with pushing off of the side of the pool and were not allowed to perform underwater turns.

Blood samples from the earlobe were taken before and 1, 3 and 5 minutes after the swim. Blood lactate concentrations were measured using an Eppendorf (Germany) lactometer. Each swimmer was filmed with a video camera at 50 frames per second acquisition rate. The camera was fixed to a push cart and pushed along the pool in parallel with the swimmer’s head. Markers at the pool side were used to calculate the distance of the head with respect to the starting wall. This position was used to calculate the clean SS (V), the stroke length (SL) and the stroke rate (SR). All three parameters were calculated only for the middle 15 meters of the pool length in order to avoid the influence of the turn and push-off at the swimming pool wall on the calculation of these parameters.

Considering the findings of previous studies (Clarys et al., 1983; Rouard et al., 1997; Caty et al., 2006) the following arm propelling muscles were chosen for recording EMG in this study: latissimus dorsi, pectoralis major and triceps brachii.

Surface EMG signals from the right pectoralis major (PM), latissimus dorsi (LD) and triceps brachii (TB) muscles were recorded; separately from the upper and lower parts of these muscles (PM1, LD1 and PM2, LD2 respectively). Bipolar Ag-AgCl surface electrodes were used (9 mm diameter discs, Hellige, Germany) with the inter-electrode distance of 20 mm. The telemetric EMG device (Biotel 88, Glonner, Germany) was fixed to a rod and carried alongside the pool above the swimmer by an assistant. The data were recorded using DasyLab 7.0 software (2002, National Instruments) at a sampling frequency of 2000 Hz.

Raw EMG signals were band-pass filtered (10 and 500 Hz). In order to obtain the amplitude and frequency description of EMG signal for each swimming stroke the active phase of a muscle was determined individually for every stroke and muscle. First the energy envelope \( E(t) \) of the rectified EMG signal \( x(t) \) was calculated using a sliding data window as:

\[
E(t_0) = \int_{t_0-125\text{ms}}^{t_0+125\text{ms}} x^2(t)dt
\]

Figure 1. Energy envelope of the rectified EMG signal of three consecutive muscle contractions of the m. latissimus dorsi during three consecutive arm strokes. Local maxima in the energy envelope and the extracted parts of the signal used for the analysis are shown.

Muscle activation within each stroke resulted in a local maximum in the energy envelope as shown in Figure 1. Active phase was defined as the part of the EMG signal for which the energy of the EMG was larger than 30% of the local maximum energy value and was used for the amplitude estimation and frequency analysis. Amplitude (ARV) of each active phase was calculated and plotted as function of time. Linear regression curve was fitted to the data and the
ARV value of the fitted curve at the time of the first and the last stroke were computed. For the frequency analysis mean frequency (MNF) was calculated. The values of MNF were plotted as a function of time. Linear regression analysis was applied to obtain the initial value (the value of MNF at the time of the first stroke) and the final value (the value of MNF at the time of the last stroke), labelled MNF$_{begg}$ and MNF$_{send}$ respectively. In order to normalize results between subjects the final values were expressed as a percentage of the initial values and labelled MNF$_{n}$.

Descriptive statistics and repeated measures ANOVA, with subsequent Tukey’s test for post-hoc analysis were used for multiple comparisons between the groups.

RESULTS

The average blood lactate values collected before and 1, 3 and 5 minutes after the swim were 1.8 ± 0.6, 6.7 ± 1.47, 12.7 ± 2.2 and 14.1 ± 2.93 mmol.l$^{-1}$ respectively. The highest lactate value collected was 17.7 mmol.l$^{-1}$.

Stroke rate (SR), stroke length (SL) and SS (S) are shown in Table 1.

Table 1. Stroke length (SL), stroke rate (SR) and swimming speed SS (S)

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>SL (m)</th>
<th>SR (stroke/min$^{-1}$)</th>
<th>SS (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>2.00</td>
<td>0.13</td>
<td>50.56</td>
</tr>
<tr>
<td>50</td>
<td>2.02</td>
<td>0.16</td>
<td>47.12</td>
</tr>
<tr>
<td>75</td>
<td>1.94</td>
<td>0.14</td>
<td>46.32</td>
</tr>
<tr>
<td>100</td>
<td>1.89</td>
<td>0.18</td>
<td>45.77</td>
</tr>
</tbody>
</table>

The ARV calculated for LD2 and TB increased significantly at the end of the swimming with respect to the beginning of swimming as shown in Figure 2, left.

Fig 2. Left: Comparison of the amplitude (ARV) of the EMG signal at the beginning and the end of 100 m all-out swim. Right: Mean MNF values with SD of MNF$_{begg}$ and MNF$_{send}$ for all muscles $^p < 0.05$.

The differences between the MNF$_{begg}$ and the MNF$_{send}$ were significant for all muscles ($^p < 0.05$, Fig. 2, right). The greatest change of MNF was detected for LD1 and TB, which decreased by 24.6 ± 8.4% (from 94.9 ± 7.3 to 69.4 ± 10.2 Hz) and by 23.4 ± 7.8% (from 102.6 ± 8.1 to 77.8 ± 10.9 Hz) respectively, and the smallest was for LD2 (from 79.7 ± 8.9 to 63.3 ± 9.4 Hz; decreased by 20.5 ± 9.1%). We found no differences in MNF$_{n}$.

DISCUSSION

In the present study fatigue of arm propelling muscles was estimated analysing some physiological, kinematic and EMG parameters.

The lactate concentrations measured in a blood samples collected after the test were comparable to other studies (Bonifazi et al. 1993) and might certificate that the maximal or at least near maximal efforts were exhibited by the swimmers. The average stroke length remained unchanged for the first 2 laps (2.00 ± 0.13 m and 2.02 ± 0.16 m respectively) and then decreased in the 3rd and 4th lap to 1.94 ± 0.14 m and 1.89 ± 0.18 m, respectively. Stroke rate decreased from the 50.56 ± 4.15 stroke.min$^{-1}$ in the first lap to the 47.12 ± 5.33 stroke.min$^{-1}$ in the second lap and then did not significantly change to the final lap. Swimming speed significantly decreased in every lap by 6.18%, 5.4% and 4.2% from the 1$^{st}$ to 2$^{nd}$, 2$^{nd}$ to 3$^{rd}$ and 3$^{rd}$ to final lap, respectively. The total average decrease of the speed from 1.68 ± 0.08 ms$^{-1}$ in the first 25 m lap to 1.43 ± 0.08 ms$^{-1}$ in the last 25 m lap was 15.0%. These results corresponded well to results of other studies (Seifert et al., 2008; Girold et al., 2006; Toussaint et al., 2006; Keskinen and Komi, 1993).

The EMG parameters obtained in our study showed signs of fatigue in monitored muscles in amplitude as well as in frequency parameters. The average ARV calculated at the end increased with respect to the values at the beginning of the swim for the LD2 and TB muscle. For LD1 and PM2 only tendencies towards such changes could be observed. The increased amplitude might be the result of the activation of additional motor units during the swimming and/or their increased synchronization. This might mean that the muscles worked at a sub-maximum level at the beginning of the swimming. Indeed, forces generated by the arm muscles during the swimming, do not present the maximum load for the muscle. The forces measured during swimming at the velocities similar to the velocities measured in our study (between 1.43m*s$^{-1}$ to 1.68 m*s$^{-1}$), were between 100 N and 120 N (Havriluk, 2004), while the isometric arm flexion force for highly trained swimmers lying prone on the bench were measured between 150 to approximately 240 N (Miyashita, 1975).

Aspenes et al. (2009) measured maximal forces 383.5 ± 89.3 N for the extensor carpi ulnaris and flexor carpi ulnaris respectively, was reported in the bilateral shoulder extension, while Girold et al. (2006) reported the average peak torque approximately 60 N/m for the elbow extension. Both studies examined groups of mixed male and female competitive swimmers. The forces produced during front crawl can be roughly estimated as sub maximal at 50% of the MVC. The increase in the EMG amplitude parameters due to fatigue has already been observed in the past: an increase of the iEMG of the deltoid muscle was found when swimming at the velocity of 1.3m*s$^{-1}$ and 1.4 m*s$^{-1}$ (Wakayoshi et al., 1994), and an increase in iEMG of a flexor carpi ulnaris muscle was found during a 4 x 100 m front crawl test at the 85% of maximum intensity (Rouard et al., 1997). In contrast to our study, the swimming intensities were not maximal in the aforementioned studies and the stimulus to the working muscles might have been insufficient to evoke greater changes of the EMG amplitude parameters of the other muscles under observation.

MNF in our study significantly decreased in all muscles under observation. The MNF decreased by 20.5% to 24.6% with respect to the initial values. Lower decrease of MNF of 11.41% and 8.55% for the extensor carpi ulnaris and flexor carpi ulnaris respectively, was reported after the 4 x 50 meters front crawl (Cayt at al. 2006). The reason for the smaller decline of MNF may be that, unlike the muscles chosen in our study, these two muscles are not propulsive muscles and their work of wrist stabilization during swimming could be less fatiguing then the work of the muscles that are responsible for propelling the body.

When comparing the amount of MNF decrease no statistically significant differences among muscles were found. Does this mean that all observed muscles fatigued to the approximately same extent during swimming? Greater fatigue was expected in LD and/or TB because of their role in the crawl arm stroke. Contraction of LD produces internal rotation, extension and adduction of the shoulder joint which is nearly a description of a crawl arm stroke (McLeod, 2010; Behnke 2001). On the other hand TB is activated during down-sweep and in-sweep enabling arm stabilization when co-contracting with biceps and to the greatest extent during the elbow extension, which is executed during the up-sweep. The up-sweep is the part of the stroke when the maximal propulsive forces (Schleihauf, 1979; Rouard et al., 1996) and the greatest forward velocities of the swimmers are measured (Maglischo, 2003).
Comparison Among Three Types of Relay Starts in Competitive Swimming

Takeda, T.¹, Takagi, H.¹, Tsubakimoto, S.¹

¹University of Tsukuba, Tsukuba, JAPAN

The purpose of the present study was to evaluate the effectiveness of no-step, single-step and double-step relay starts for swimmers. Eight male collegiate swimmers participated in the present study. For each type of start, each swimmer performed six trials of relay starts with maximum effort. Ground reaction forces were measured using a Kistler force plate to calculate the take-off velocity and take-off angle from the force data. Relay times were measured by counting the number of video frames obtained by a high-speed camera. No significant difference in the horizontal take-off velocity was observed. The relay times decreased significantly in the order no-step, single-step and double-step starts (P < 0.05). Eight trials among all the trials for the step starts resulted in incorrect foot placement on the edge of the block. No-step starts resulted in better performance than step starts.

Key words: Step start, Relay time, performance

INTRODUCTION

In relay events, it is possible to record a time on the starting block (block time) of zero second. The block time is the time that elapses between the instant at which the start signal is given and the instant at which the swimmer's foot leaves the starting block. In relay events, the first swimmer begins the race when the start signal is given, and swimmers to follow start after the previous swimmer has reached his or her finishing point. Therefore, the time on the block of the swimmers to follow should ideally correspond to the instant at which the previous swimmer reaches his or her finishing point. The block time of an individual in regular events ranges from approximately 0.6 to 0.8 s, as reported in previous studies (Issurin & Verbitsky 2003, Takeda & Nomura 2006). The results of relay events depend upon the technique adopted while changing swimmers during a relay. The sum of the block times in the three changeover swimmers represents approximately 2.4 s.

There are two kinds of starting techniques in relay events. Their starts generate greater horizontal velocity upon take-off from the starting block (McLean et al. 2000). The swing start involves the swing of an arm. On the other hand, the step start involves taking one or two steps before jumping with both feet from the block. There have been a few studies on relay starts (Gambrel et al. 1991, McLean et al. 2000). McLean et al. (2000) investigated the effectiveness of step starts in the case of collegiate male swimmers who were given instruction on step starts over a four-week period. These researchers reported that step starts were effective relay starts. However, they did not consider the relay time when evaluating the start performance.

The step start is considered a more difficult technique than a start involving no steps (no-step start) because swimmers often place their foot on the edge of the starting block by mistake. The swimmer cannot generate satisfactory horizontal velocity on the block if the foot placement is incorrect. It is necessary to determine the best relay start by taking into consideration the time taken to change swimmers during the relay and the difficulty each swimmer faces in the step start. The purpose of the present study was to evaluate the effectiveness of the three types of relay starts in order to determine the relay start performance while considering the relay time and the difficulty faced during step starts.

METHODS

Eight well-trained male college swimmers participated in this study. Their mean height, mean body weight and mean age were 177.9 ± 5.7 cm, 74.1 ± 5.7 kg and 19.8 ± 1.1 years, respectively.
cm, 73.1 ± 6.4 kg and 20 ± 1.2 years, respectively. Before the experiment began, each swimmer received instruction on the no-step start and two types of step starts over a two-weeks; this was achieved by conducting daily training sessions. In each trial of a relay start, swimmers were permitted to swing their arms and to perform counter-movement.

In the trial, we select three relay starts: a no-step start (NS), single-step start (SS) and double-step start (DS) (Figure 1). For each start technique, each swimmer performed six trials with maximum effort; the trials were performed in random order. Each swimmer executed the relay start trial by timing it with the goal touch of the previous front crawl swimmer and then sprinted 15 m by front crawl swimming.

**No-step start**

**Single-step start**

**Double-step start**

Figure 1. Three types of relay starts performed in this study.

Two high-speed cameras (FAST-CAM PCI, Photron Inc., JAPAN) filmed the trials at 250 frames per second. Camera 1 was positioned such that its optical axes were perpendicular to the plane of motion. Camera 2 was positioned 2.5 m above the floor of the side pool deck and filmed the scene at the instant at which the incoming swimmer touched his finishing point and the outgoing swimmer take-off from the starting block. The relay time was defined as the time elapsed between the touch and take-off and was calculated by counting the frames in the video image captured by Camera 2.

Ground reaction forces during the relay starts were sampled at 1000 Hz by a waterproof force plate (5253B11, Kistler JAPAN Inc.) that was modified into the starting block. The force data were smoothed using a low-pass Butterworth digital filter with a low pass cutoff frequency of 40 Hz. The velocity at take-off (take-off velocity) was calculated from the data on the ground reaction force by performing time integration until the time of take-off. The take-off angle was defined as the angle between the resultant take-off-velocity vector and horizontal line (upward direction: positive, downward direction: negative). The horizontal ground reaction forces were used to distinguish the forces generated by steps or the body leaning forward and the legs driving out. The force generated by legs driving forward was defined as the force after the time \( t_f \) when the horizontal ground reaction force reached over 30% of body weight. The force before \( t_f \) was obtained as the force by step or body leaning forward (Figure 2). The horizontal reaction force generated by the legs driving was integrated with respect to time, and this value was used to calculate the velocity generated by the legs driving. A one-way repeated measure ANOVA was performed for the start type; this was followed by Bonferroni multiple comparison in each variable. The statistical significance was set at \( P < 0.05 \).

**RESULTS**

Table 1 lists the mean horizontal take-off velocity, take-off angle and relay time in each trial. The relay times were increased significantly in order of no-step start, single-step start and double-step start. The horizontal velocity generated by legs driving in the no-step start was significantly greater than that in the double-step start. There was no significant difference in the horizontal take-off velocity and take-off angle. Table 2 lists the mean values of the standard deviation in the six trials for each condition.

**Table 1. Mean values of horizontal take-off velocity, horizontal velocity generated by legs driving, take-off angle and relay time in each trial.**

<table>
<thead>
<tr>
<th></th>
<th>Horizontal take-off velocity ((m/s))</th>
<th>Horizontal velocity generated by legs driving ((m/s))</th>
<th>Take-off angle ((^\circ))</th>
<th>Relay time ((s))</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-Step</td>
<td>0.15 ± 0.08</td>
<td>0.10 ± 0.05</td>
<td>-11.12 ± 6.15</td>
<td>0.054 ± 0.023</td>
</tr>
<tr>
<td>Single-Step</td>
<td>0.25 ± 0.09</td>
<td>0.15 ± 0.06</td>
<td>-13.18 ± 5.27</td>
<td>0.052 ± 0.044</td>
</tr>
<tr>
<td>Double-Step</td>
<td>0.15 ± 0.08</td>
<td>0.10 ± 0.05</td>
<td>-13.70 ± 4.80</td>
<td>0.087 ± 0.060</td>
</tr>
</tbody>
</table>

\(*: P < 0.05 in comparison with single-step start trials.\\†: P < 0.05 in comparison with no-step start trials.\)

Table 2. Mean standard deviations of horizontal take-off velocity, horizontal velocity generated by legs driving, take-off angle and relay time in each trial.

<table>
<thead>
<tr>
<th></th>
<th>Horizontal take-off velocity ((m/s))</th>
<th>Horizontal velocity generated by legs driving ((m/s))</th>
<th>Take-off angle ((^\circ))</th>
<th>Relay time ((s))</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-Step</td>
<td>0.15 ± 0.08</td>
<td>0.10 ± 0.05</td>
<td>-11.12 ± 6.15</td>
<td>0.054 ± 0.023</td>
</tr>
<tr>
<td>Single-Step</td>
<td>0.25 ± 0.09</td>
<td>0.15 ± 0.06</td>
<td>-13.18 ± 5.27</td>
<td>0.052 ± 0.044</td>
</tr>
<tr>
<td>Double-Step</td>
<td>0.15 ± 0.08</td>
<td>0.10 ± 0.05</td>
<td>-13.70 ± 4.80</td>
<td>0.087 ± 0.060</td>
</tr>
</tbody>
</table>

**DISCUSSION**

McLean et al. (2000) reported that the horizontal take-off velocity after the double-step start was significantly greater than that after the no-step start. Our hypothesis was similar to the results of McLean's study. However, there was no significant difference among the horizontal take-off velocities achieved by the three relay start techniques (see Table 1). The advantage of step starts is that horizontal forces are generated until the legs driving starts, whereas there was no significant difference in the horizontal take-off velocity and take-off angle. Table 2 lists the mean values of the standard deviation in the six trials for each condition.

Figure 3 shows the changes in the ground reaction force until take-off, as a typical example for Sub. A. Similar patterns were observed when the three trials involving the other subjects were compared. For all subjects, there were a total of eight trials for each step start.

Figure 2. The definition of the horizontal ground reaction force generated by taking steps and leaning forward and the force generated by the legs driving.
The mean values of the standard deviations for each trial were small. Participants in the present study adopted an effective technique in relay starts. Although there were significant differences in the relay times, these differences were not very large. They may be related to the time elapsed during the step start until take-off, because the step starts involve a greater number of movements associated with stepping to the edge, adjusting the foot placement on the edge, and jumping into the pool. In eight trials among all the trials for all starts, the foot placement was incorrect. This indicates that the degree of difficulty of the step start is higher than that of the no-step start. Therefore, the no-step start is better for achieving consistent and superior performance in an relay event within actual competition.

However, a step start may help achieve greater horizontal take-off velocities. Swimmers should apply the technique aimed at generating a greater horizontal force within a shorter duration of leg driving. It is also advantageous to achieve a certain amount of horizontal velocity by stepping, improve the accuracy while placing both feet and to achieve grip by using both feet correctly on the edge of starting block.

**CONCLUSION**

The take-off velocity generated by the step start was not higher than that achieved by the no-step start. In step starts, the time required to change swimmers in a relay was significantly longer than that in no-step starts and there were eight failed trials (SS, DS). Therefore, the no-step start is better than the step start since it helps achieve consistent and superior relay start performance.
A Study About the 3D Acceleration in Front Crawl and its Relation With Performance

Tella, V., Madera, J., Colado, J.C., Mateu, J., Garcia Massó, X., González, L.M.

Universidad de Valencia, Valencia, España

The objective of this study was to analyze the acceleration of the hip generated during front crawl. The swimmers (n=71) performed 25 meters at maximum speed. 3D acceleration was registered. Swimming time domain acceleration signal was analyzed. Root Mean Square (RMS) parameter was calculated in the three directions. Also, RMS indexes were calculated to relate the directions in two's. The results showed differences between the different parameters. Speed correlated positively with the RMS values: anterior-posterior (X), medium-lateral (Y) and superior-inferior (Z) directions (p<0.01). Also, statistical relations were found among the indexes that relate the X and Y (p<0.01) acceleration directions and the X and Z (p<0.01). To conclude, 3D acceleration analysis may indicate the efficiency during front crawl.

Key words: 3d acceleration, efficiency, front crawl swimming.

INTRODUCTION

In swimming, kinematic variables that are obtained during a cycle have been used to study the coordination (Chollet et al., 2000), the different cycle phases length or velocity changes (Leblanc et al., 2007) or the propulsive efficiency in physiological terms (Barbosa et al., 2005) or biomechanical terms (Vezos et al., 2007). Seifert et al. (2004) suggested that the methodology for the study of the intra-cycle velocity may show the coordination of the applied forces during swimming.

With the aim of characterizing the frequency front crawl applied forces, Tella et al. (2008) measured and analyzed the produced acceleration in the swimming direction. These authors also focused on the time domain analysis of the swimming acceleration, showing that the amplitude of the acceleration might be influential directly on the speed.

Nevertheless, the fact of limiting the generated forces only in one direction reduces the possibilities of interpretation. According to Handford et al. (1997), time coordination of the arms and legs can be "anti-phase" (i.e. right arm with left leg or right leg with left arm) or "in-phase" (i.e. left leg with right arm or right leg with left arm). Possibly, the asynchronous action of one of the arms (Nikoldi et al., 2005) might make in the "anti-phase" actions not only anterior-posterior (X) accelerations but also medium-lateral (Y) accelerations. However, no matter the simultaneous actions of the arms with the legs during "in-phase", coordination might originate basically displacements in X and upper-lower (Z) directions.

The aim of this work was to analyze the relationship between the acceleration in the X, Y and Z of front crawl swimmers. Additionally, we described the RMS in each swimming direction to establish their differences.

METHODS

Seventy swimmers (38 male and 32 female; age: 16.29 ±3.07 years) participated voluntarily in this work. The triathletes competed at regional and national level. All the protocols carried out in this study fulfilled the requirements of the Helsinki Declaration of 1975, lately revised in October 2000.

The triathletes swam a 25 m test at maximum speed. This test was made in a 25 m pool with water start. Swimmers warmed up before the test during approximately 20 minutes.

MEGA 6000 T4 equipment was used to register the acceleration during the 25 meters test. For measuring the swimming velocity, the displacement of the swimmer was recorded with a video camera (25 frames per second). An acceleration module (3 axes, range ±10G, sample frequency 1000 Hz) was used for this study. The registering system for the acceleration was secured in an AQUAPAC waterproof bag (250x135x265 mm). The accelerometer was set between the first and the third lumbar vertebra to register the X, Y and Z direction of the acceleration during the test.

Data was analyzed off-line using specially designed software based on Matlab 7.1 (R14) (Mathworks Inc., Natick, USA). The acceleration signal was analyzed in the time domain. For X, Y and Z registered acceleration signals, only five central seconds were selected from each 25 meters test. The magnitude of the acceleration was analyzed through the average root mean square (RMS) value, processed in 100ms size blocks in all three directions.

Based on the time parameters, an index was obtained to relate the acceleration values between directions. Specifically, each one of them has been calculated through the quotient between the average RMS values of the related directions. Thus, the RMS Index between X and Y directions (IRMSX/Y) is the result of dividing the RMS value in X direction by the RMS value in Y direction (IRMSX/Y=RSMSX/RSMSY). The RMS Index between X and Z directions (IRMSX/Z) is the result of dividing the RMS value in X direction by the RMS value in Z direction (IRMSX/Z=RSMSX/RSMSZ). And the RMS value between Z and Y directions (IRMSY/Z) is the result of dividing the RMS value in Z direction by the RMS value in Y direction (IRMSY/Z=RSMSZ/RSMSY).

The statistical analysis was performed with the SPSS software, version 12.0 (SPSS Inc., Chicago, Ill., USA). Descriptive statistics and a one-way ANOVA were applied. The ANOVA was performed through Bonferroni post- hoc tests, because of its control over the Type I error and its strength when the number of comparisons is small. All differences with p<0.05 were accepted as statistically significant and those with p≤0.01 as very significant. The possible relations between the different variables were established with a Pearson correlation coefficient.

RESULTS

The swimmers registered a speed of 1.45±0.02 m·s⁻¹ during the central part of the 25 meters test. Acceleration data in the three directions converted in RMS values in each direction. Descriptive data and their statistically significant differences can be observed in Table 1.

Tabla 1. Analysis of acceleration 3D in the time domain

<table>
<thead>
<tr>
<th></th>
<th>n (70)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSX</td>
<td>1.71±0.05</td>
<td>RMSX-RMSY*</td>
</tr>
<tr>
<td>RMSX</td>
<td>4.92±0.17</td>
<td>RMSX-RMSZ*</td>
</tr>
<tr>
<td>RMSX</td>
<td>2.30±0.12</td>
<td>RMSX-RMSZ*</td>
</tr>
<tr>
<td>RMSY</td>
<td>3.26±0.12</td>
<td>RMSY-RMSZ*</td>
</tr>
<tr>
<td>RMSZ</td>
<td>3.20±0.12</td>
<td>RMSZ-RMSY*</td>
</tr>
</tbody>
</table>

Table 2 shows the descriptive data of the different studied indexes and their statistically significant differences.

Tabla 2. Analysis of index acceleration 3D

<table>
<thead>
<tr>
<th></th>
<th>n (70)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRMSXY</td>
<td>0.48±0.02</td>
<td>IRMSXY*</td>
</tr>
<tr>
<td>IRMSXZ</td>
<td>1.34±0.05</td>
<td>IRMSXZ*</td>
</tr>
<tr>
<td>IRMSXY</td>
<td>0.36±0.01</td>
<td>IRMSXY*</td>
</tr>
<tr>
<td>IRMSXY</td>
<td>0.36±0.01</td>
<td>IRMSXY*</td>
</tr>
</tbody>
</table>

IRMSXY index that relates RMSX and RMSY; IRMSXZ* index that relates RMSX and RMSZ; IRMSXY index that relates RMSZ and RMSY; *p<0.01
The velocity, as a parameter that determines the final swimming performance, showed a positive correlation with some of the studied statistical data of the acceleration (Table 3).

**Table 3. Correlation variables (r de Pearson), time domain analysis, index and swimming velocity.**

<table>
<thead>
<tr>
<th>v</th>
<th>0.51*</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS z</td>
<td></td>
</tr>
<tr>
<td>RMS y</td>
<td>0.40*</td>
</tr>
<tr>
<td>RMS x</td>
<td>0.60*</td>
</tr>
<tr>
<td>IRMS x/y</td>
<td>0.36*</td>
</tr>
<tr>
<td>IRMS x/z</td>
<td>0.43*</td>
</tr>
<tr>
<td>IRMS y/z</td>
<td>0.03</td>
</tr>
</tbody>
</table>

*p<0.01

**DISCUSSION**

Quantifying the swimmers’ performance has been approached from different points of view. One of them, the biomechanical analysis of the propulsive forces, has been highly relevant since Schleihauf (1979). Up to date, however, there are only few studies that considered the importance of acceleration as a key parameter in this matter. The accelerations and decelerations obtained during the front crawl displacement are the result of the force exerted by the swimmer and by the swimmer’s interaction with the environment (Bixler & Reiwald, 2002; Silva et al., 2008).

A recent study carried out by Tella et al. (2008) showed some possibilities. As an efficient acceleration value, the authors argue that the root mean square (RMS) parameter is a good predictor of performance. In that work, acceleration was derived from the swimming speed, so the data is directly related to the intra-cycle velocity. In the present study, acceleration data has been directly obtained from the result of the different forces that interact on every cycle. That is probably why the RMS values are not meant to be closely related to the intra-cycle velocity. The data of the present study show lower RMS values than those obtained in the aforementioned study. This difference may be due to several explanations. The average speed of both studies differs a 10%. Body position during swimming may differ because of the 0.250 g resistance of the speedometer in Tella et al. (2008). The main coincidence of both studies is the statistical relation between the magnitude of the RMS parameter and the speed that swimmers reach. In spite of registering weaker relationships, our data reinforce the ones obtained in the aforementioned study, because of the positive relations in the X swimming direction in our study.

Although the swimmers' body positions were not measured, the information that comes from the statistical relation between swimming speed and the different studied indexes suggests that the efficient values of the acceleration in the X direction (RMS X) should be closer to the Y direction values (RMS Y) and should be greater than the Z direction (RMS Z) values, to obtain higher speeds. If in this study, the difference between RMS X and RMS Y values were 52%, then the most efficient swimmers would be the ones that obtain lower percentage difference between both values. So, if the obtained difference between RMS X and RMS Z directions were 34%, the most efficient swimmers would be the ones that obtain higher percentage difference between both values. These indexes relate the accelerations in the different swimming directions may show a better coordination effectiveness of the “in-phase” and “anti-phase” actions related to the propulsive movements in front crawl swimming. From the above, it seems to emerge a clear practical application: these indexes may be sensible to the modification of determined technical or coordinative patterns of front crawl swimming, and they may also give us information about the major or minor propulsive efficiency.

This study presents two limitations. On the one hand, a box fixed to the body which changes its shape and position per cycle, may not behave like the body to which it is fastened. On the other hand, a box fixed to the body is interacting with water mass which is whirling around and thus the signals are also influenced by wobbling water mass.

**CONCLUSION**

The RMS appears to be a determining parameter for front crawl swimming. The indexes that relate the accelerations obtained in the different swimming directions may give us relevant information about the acceleration efficiency in front crawl swimming. However, future studies should be done to validate these data through video-photogrammetry.

**REFERENCES**


Aquatic Space Activities (ASA) is a collective term for activities in water such as: Competitive – Recreational – Masters swimming, Endurance swimming, Triathlon, Scuba-diving or Water-exercises. ASA must obey flow physics. Traditionally, flow physics in aquatic sports is confined to steady conditions assuming that the flow velocity is constant and the body is rigid. It is not new information that this is not and was never the case in human swimming. The fact is that the limbs change motion in a steady situation). From practical experience it is known that “unpredictable” (also when the displacing action causes the change) is (completely) different. According to the law of conservation of mass, in a flow, water cannot be pushed away in relation to the surrounding water. Nevertheless it is true that, where there is one solid body (like a swimmer's hand) there cannot be another body. However, where does mass of displaced water go? The aim of this paper is to introduce some facts of flow physics, beyond our understanding of the existing biomechanical aspects, and relevant for a better understanding of aspects of aquatic space activities and the reaction of water-set-in-motion.

METHODS
Swimming text books mostly provide a chapter related to biomechanical background of activities in aquatic space. It is curious that over the decades, the content of this chapter, including pictures has not really changed from the very first publication of the author and coach “Doc” Counsilman. Obviously these text books were so convincing worldwide that later authors had no reason to change this. In nearly the same decades numerous studies have been presented in the congress series of biomechanics and medicine in swimming, it seems as if their outcome is of minor relevance.

During the same time period in parallel, much research was done in the field of swimming animals. Researchers in this field, starting with similar assumptions to their colleagues in human swimming, soon became aware that the steady flow approach was not helpful in answering their questions. The alternative approach, mostly based on concepts published by Lighthill, opened a quite new route to structuring the research and to study unknown hydrodynamic features related to self-induced propulsion. Some of these results have held and can act as a guideline in swimming literature, because the myths and the impact on swimming technique are considerable. Coaches and researchers may mislead their swimmers when still following the ancient concepts.

RESULTS
Let’s consider the properties of water mass. It has long been known that aquatic space is characterized, like any body, by mass and other features. Firstly, water has the property to change shape. Any body, e.g. the hands or feet, even when moving relative to water, displaces some water-mass. This means the motion of the water (in the vicinity to the moving body) is changed and flow is created: if water is at rest (before it is displaced) this is also true: what counts is the relative change of motion. Since the relative motion between the body and water is essential, research on aquatic activities executed in a flume also applies to activities in a pool. Pressure is an important feature of water at rest and in motion: the weight of the water mass displaced by a body submerged in water exerts a force due to water pressure in an upward direction, called buoyancy. A body, submerged and moving relative to water produces a change of pressure and due to that change “some” particles are set into motion. Based on the continuity-pressure-concept, the pressure causes and maintains a flow, a continuous movement of the fluid from one place to another. According to Euler (1707 - 1783) particles-in-motion (i) possess mass, weight, acceleration, velocity, etc. and (ii) occupy some space in the vicinity of the moving body (whereas the rest of the water-mass remains undisturbed).

The space of particles-in-motion is full of vectors and scalars, forming vector fields.
all particles set in motion. **Momentum** is a vector; the magnitude is the product of mass (m) times its velocity (v): $m \cdot v = kg \cdot m/s = N \cdot s$ and its direction coincides with the direction of the velocity.

The **momentum** approach allows for application of the law of conservation of momentum (original enunciation: René Descartes (1596-1650)). According to this principle the total momentum is constant – provided a closed system is considered (which is not subject to external influence). If two (or more) masses belong to a closed system (Figure 2) and one mass changes velocity, simultaneously the other masses will adapt their momentum (in the opposite direction), hence, any interaction between body and surrounding water gives a reaction. The actions of (parts of) any body in aquatic space transmit energy while changing the motion of water-mass over a period of time. The simultaneous reaction has an effect in and against the swimming direction at the same time. If increasing speed of a whole body is observed, there will be a zero “net” effect in swimming direction.

The principle of momentum claims that if the momentum before and after an interaction of limbs and water-mass differs this difference is induced by the interaction. This concept is elegantly applied to determine effects of a “displacing” rigid total body on a flow of constant speed, either in steady or unsteady conditions. Based on the law of conservation of momentum it is evident that momentum in front of the whole body must be equal to the momentum in the wake plus all momentum changes produced by the interaction between total body and particles-in-motion. The difference in momentum over time in steady flow is called drag or propulsion (Figure 3).

Jet-propulsion in aquatic space: In context with induced water motion it was pointed out that body actions change the motion of water-mass due to interaction of the limbs and water-mass. The effect of the interaction of limbs and water-mass is a change of momentum. From this it follows that the change of momentum of particles (m-\*v') are combined with a change of momentum of the total body mass (m-\*v), in the opposite direction. From the swimmers view the reaction (m-\*v') provides components in and against the swimming direction (called drag or thrust). If the momentum of particles (m-\*v) is totally directed against the swimming direction of the total body, the reaction results in a 100 % effect. Water moving backwards is thrusting the whole body forward. However, this does not suggest that one should move the hand or leg backwards to gain an effective thrust. The most effective and efficient way to gain maximum thrust for a given energy-input is a jet-flow, used by squids or jelly fish (Fig . 3).

Jet-flow is a powerful stream of mass carrying high momentum. Jet-propulsion exists also in the swimming of the skilled human. Matsuuchi et al. (2004) published research data for the first time based on the PIV-method (Particle Image Velocimetry), demonstrating the existence of intermittent jet-flow. Close scrutiny revealed that first a vortex-ring had to be produced by the action of the swimmer's hand and in its wake. The rotation of the vortex rings cause a particle drift in one direction. The shape and rotation of the vortex ring determines the jet length-to-diameter-ratio and thus the momentum. Hence, the orientation of the jet-flow relative to swimming direction determines the contribution to thrusting the body.

**DISCUSSION**

Concentration on the interaction of limbs and water-mass instead of limiting oneself to the mere action of limbs or bodies, augments the understanding of reality. The act of understanding is a dynamic process and prone to verification / falsification of theories. The saying, nothing is more practical than a good theory, is valid when theory mirrors reality. Sometimes a change in theory means that already existing, but not established concepts survive; e.g. Berger (1996, 95) found that high propulsive forces cannot be based solely on lift and drag of an acting hand and concluded “the key to producing effective propulsion at low energy cost may be the creation of vortices of a special form”.

The research of jet-flow requires a water-related view of both the motion of the limbs and of the water-in-motion in aquatic space. Most of the existing studies on swimming use a body related approach focusing on the velocity of body actions. In most studies related to swimming the understanding of the movement of the surrounding water is limited to the lift and drag approach, established in 1970 by Coussilman. Already in 1986 Coussilman said in personal communication: “I can’t help it if people still refer to my publications of the end of the sixties”. He was aware that the drag and lift approach was not applicable to an unsteady swimming situation. In that time the vortex induced propulsion concept and influence of added mass to swimming bodies started to attract the interest of (a few) swimming researchers. Ungerechts (1988) published the idea that breaststrokers’ leg actions lead to rotating water forms by which “momentum is transferred to the fluid and in reaction, its “impulse” accelerates the body.” Van Tilborg et al. (1988) presented data of “impulses”, measured in Ns, resulting from the difference between propulsion and resistance for different phases in breaststroke. They pointed out that “impulses are more reliable than forces”. Ungerechts (1992), calculated momentum needed to change hip motion (\(\Delta v\)) during the arm stroke including an inertial term due to acceleration based on experimental data of eight breaststrokers and compared the data with forces due to the hands’ actions. It was shown that momentum = [16.5 – 45.9] Ns will explain (\(\Delta v\)) = [0.27 – 0.76] m/s with 93 % confidence. Ungerechts & Klauck (2006) presented the flow physical laws which are relevant for unsteady flow in conjunction with added mass effects.

A change of paradigm from a body related to a water related view
consider the effects due to displacement of water in addition to repulsive effects. The latter are not neglected but qualified. Humans can perform well in an aquatic space without knowing the details of flow physics. It is a different case however when instructors or coaches are not well informed about the relevancy of the interaction of limbs and water-mass and its reaction. In particular the illiteracy of the momentum aspect, only about ten papers in 36 years of the Conference Series of Biomechanics and Medicine of Swimming have handled this topic, is not helpful.

The water related view also tackles the terminology of rules of stroking written for the referees in swimming. This terminology still uses the concept of pulling and pushing arms, whereas e.g. the BMS conference series revealed that sculling actions of the hands dominate all strokes. Of course each expert is free to select any terminology. But a more appropriate terminology supports the mental representation of strokes required to execute and control movements.

CONCLUSIONS

The increase of knowledge of effects of ASA in the last decade is remarkable and resembles a change in paradigm. The traditional paradigm is body orientated and concentrates on the biomechanical aspects of body motion. ASA related sports like Recreational swimming, Finswimming, Triathlon, Scuba-diving or Water-exercises seem still to be far from the water related view, still relying on the established $u^2$-law of resistance. This approach is an acceptable pedagogical view, searching for best solutions as to how to teach swimming and stroking correctly. Bridging the gap and approaching a water related view including unsteady features of flow seems to be difficult.

The vortex-ring like structure created by hand-action demands a turning around action of the hand, a kind of supination or pronation, during the period of underwater action. Since all activities performed in aquatic space will face more or less the same conditions, it is concluded that unsteady flow physics should become the basis of further research, independently of biomechanical or physiological issues. This continued research needs also to be phrased in terms permitting it to be accepted by practitioners.

REFERENCES


ACKNOWLEDGMENTS

The authors would like to thank Dr. Huub Toussaint from Swimming Research Center Amsterdam, The Netherlands, for valuable information and suggestions to accomplish this paper.

Analysis of Swim Turning, Underwater Gliding and Stroke Resumption Phases in Top Division Swimmers using a Wearable Inertial Sensor Device

Vannozzi, G.¹, Donati, M.², Gatta G.² & Cappozzo, A.¹

¹ Department of Human Movement and Sport Sciences, University of Rome "Foro Italico", Italy
² Faculty of Exercise and Sport Science, University of Bologna, Italy

Improving performance is a difficult task for elite swimmers. The study of turning, underwater gliding and stroke resumption kinematics may lead to the reduction of the relevant durations. Common video analysis is sometimes inadequate to investigate motor tasks. This work aimed at describing the mentioned phases in top division swimmers using a wearable inertial device. Eight elite swimmers were selected so as to cover all the four swimming styles. The device was positioned on the lower trunk and a 50m trial at the maximum velocity was executed. The angular velocity about each axis was post-processed and both time and kinematic parameters were extracted for each phase, characterizing each swimming style. Strength points of the approach are: simple description of the turning kinematics; possibility to extract performance-related parameters; simplicity of use for the operator; the minimal encumber for the athlete.

KEY-WORDS: inertial sensor, angular velocity, turning, kinematics

INTRODUCTION

Improving athletic performance is one of the main goals of sport biomechanics, in general, and of swimming research, in particular. This goal is more difficult to obtain as the elite swimming level increases, thus chances for improvement are relatively limited. However, closely examining swimming aspects such as turning, underwater gliding and stroke resumption phases, and investigating how the relevant timing might be optimised for improving the overall swimmer performance, may provide valuable information to the coach. This circumstance was remarked by Lyttle et al. (1999) who stated that "little changes on the turning action performance can imply substantial improvements of the final event time". The goal of deepening knowledge into the mentioned swimming phase can be obtained if an accurate way to describe the kinematics of the abovementioned swimming phases is made available.

Among the mentioned swim phases, turning is one of the most critical to be analysed. Turning mechanics is usually described using force plates embedded in the pool wall (Takahashi et al., 1982), to obtain forces and torques during the push-off phase that follows the rotational phase. Both flip-turns and open turns are complex movements, usually investigated - with great difficulty - using video analysis. In fact, due to the aquatic environment, refraction of the water, as well as actions of several body segments, which are moving in different movement planes (Pereira et al., 2008), it is not rare to experience serious difficulties in tracking the selected skin markers. Moreover, video analysis usually requires a complex instrumental set-up and a massive computational effort to obtain the desired biomechanical quantities. For these reasons, this important phase of a swimming competition is scarcely dealt with in the scientific literature.

Following the recent trend of implying wearable inertial devices in human movement analysis, also swimming research recently started to include such sensors in experimental setups. Ohgi and colleagues (2003) used a tri-axial accelerometer positioned on the wrist to carry out a phase segmentation of breaststroke trials. The feasibility of using a 3D accelerometer mounted on the pelvis was demonstrated by Slawson et al. (2008), who succeeded in characterising pelvis linear accelerations in different swimming styles. At this stage of research, the available applications dealt only with linear accelerations and there is no evidence on how the mentioned swimming phases might be characterized using inertial sensor devices.

This work aimed at quantitatively describing the swim turning, underwater gliding and stroke resumption phases in top division swimmers using a wearable inertial device composed of a tri-axial accelerometer and gyroscope. This objective entailed the definition of appropriate parameters that could be effectively used by the coach to compare different swimming techniques towards total-time minimisation.

METHODS

Eight elite swimmers (four males and four females) volunteered to participate in the study. The athletes are part of a top division Italian team and were selected so as to cover the four swimming styles (freestyle, backstroke, breaststroke and butterfly).

Participants wore the FreeSense device (Sensorize, Italy) which is a wearable measurement instrument equipped with a tri-axial accelerometer and two bi-axial gyroscopes, weighing 93g and fully portable (size: 8.8 x 5.1 x 2.5 cm), allowing to perform the swimming task in the most natural fashion (as depicted in Figure 1). Once water-proofed, the device was incorporated into an elastic (neoprene) belt which was fastened around the participant’s waist, at the dorsal side of the trunk at the fourth lumbar vertebra level. In Fig.1 the device positioning is represented together with the definition of the local reference frame. The device output were three linear accelerations along the three local axes and three angular velocities (ω_x, ω_y and ω_z) about the same axes.

Figure 1: Device positioning on a swimmer low trunk and definition of the local frame of reference.

Data were collected with a sampling frequency of 100 Hz and were saved directly on board of the device. A commercial video camera and a chronometer were also used to video-record each trial and to record the relevant time duration (t_p), respectively. All data collection was performed in a 25m swimming pool.

After familiarisation with the instrument, each participant was asked to perform a 50m trial at his/her maximum velocity as during a real competition.

In this study, temporal and kinematic parameters were mainly obtained using angular velocities about the three axes of the local frame of reference. For each swimming style, the following parameters were extracted for the different phases:

- Gliding phase - duration of first and second lap, respectively t_glide1 and t_glide2
- Stroke phase - duration of first and second lap, respectively t_stroke1 and t_stroke2
- Turning phase - duration, t_turn, peaks of angular velocities p_x, p_y and p_z; time interval between the main two angular velocity peaks, t_p.

The parameter selection procedure is depicted in Figure 2 considering a randomly selected backstroke trial that includes the execution of a flip-turn technique. The same procedure was also reported in Figure 3 for a butterfly trial, including an open-turning execution. Even if only angular velocities were used in this paper, similar considerations can be made to extract appropriate parameters from measured local accelerations.

178
RESULTS
Each swimmer completed the execution without problems and did not experience any difficulty in using the instrumental apparatus. Results for the eight swimmers are listed in Table 1. Positive and negative \( \theta_0 \) values are according to the convention in Fig 1.

Table 1. Results obtained for the four swimming styles for each selected parameter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Freestyle</th>
<th>Breaststroke</th>
<th>Backstroke</th>
<th>Butterfly</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \omega_x ) (deg/s)</td>
<td>-119</td>
<td>-230</td>
<td>-140</td>
<td>-230</td>
</tr>
<tr>
<td>( \omega_y ) (deg/s)</td>
<td>-265</td>
<td>-321</td>
<td>-260</td>
<td>-260</td>
</tr>
<tr>
<td>( \omega_z ) (deg/s)</td>
<td>-238</td>
<td>-260</td>
<td>-128</td>
<td>-128</td>
</tr>
<tr>
<td>( \omega_{pp} ) (deg/s)</td>
<td>0.66</td>
<td>0.54</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>( t_{pp} ) (s)</td>
<td>1.14</td>
<td>1.18</td>
<td>1.36</td>
<td>1.26</td>
</tr>
<tr>
<td>( t_{g} ) (s)</td>
<td>51.60</td>
<td>58.07</td>
<td>56.07</td>
<td>44.44</td>
</tr>
<tr>
<td>( R )</td>
<td>1.01</td>
<td>0.36</td>
<td>0.36</td>
<td>0.35</td>
</tr>
</tbody>
</table>

DISCUSSION
The present study verified the feasibility to use wearable inertial sensor devices to characterise turning, gliding and stroke resumption in swimming. The novelty of the approach is constituted by the use of gyroscopes to measure angular velocities and by the consequent easy description of swimming rotational movements. If used in conjunction with the available measured linear accelerations, several biomechanical parameters can be extracted that increase the knowledge about each swimming style and/or about the strategy adopted by each swimmer. Several quantitative parameters were selected from the sensor device output: the choice reflected the need to characterise each swimming style and offer possible parameters to describe the way each athlete executes his/her swimming exercise.

Highest \( \theta_0 \) were found for freestyle in both genders. This circumstance is directly related to the well-known highest velocities usually obtained in this swimming style at the end of the 25m lap. This parameter was higher for males than for females, as it happens usually for mean velocity; even if related differences are smaller than for linear velocity. In fact, the two parameters are linked by the equation \( v = \theta \omega R \) - being \( R \) the distance between the most external point and the rotational axis and, thus, related to the individual flexibility. Considering that females are usually more flexible than males, thus more able in reducing \( R \), it is possible to argue that a higher \( R \) for female compensates the higher mean velocity usually obtained by male swimmers. The sign of the rotation depends upon the style: freestyle and backstroke use a flip-turn technique, thus involving a positive rotation about the cranio-caudal axis, consistently with its open-turn technique used for these two styles: after the feet contact on the pool wall, the swimmer suddenly turns the upper body leading to the rotation using the right arm, thus generating a clockwise rotation about the z axis corresponding to the recall of the leg before the push-off.

Further peak angular velocities, \( \omega_{pp} \), characterised differently the other swimming styles. Highest \( \omega_{pp} \) were found for the backstroke flip-turn that is first characterised by a sudden rotation about the cranio-caudal axis, consistently with its theoretical execution. For all styles, the negative peak indicated that every athlete carried out the rotation leading the right arm, thus executing a clockwise rotation about the cranio-caudal axis. This is, in fact, a choice dependent upon the single swimmer. Highest \( \omega_{pp} \), conversely, were found for both breaststroke and butterfly, this circumstance is consistent with the open-turn technique used for these two styles: after the feet contact on the pool wall, the swimmer suddenly turns the upper body leading the rotation using the right arm, thus generating a clockwise rotation about the x axis (negative \( \omega_{pp} \) peak).

Still focusing on the turning phase, \( t_{pp} \) and \( t_{g} \) were higher for backstroke, consistently with the backstroke turning technique that includes a rotation (positive if clockwise, negative if counter-clockwise) about the X-axis before the execution of the rotation about the Y-axis. Also, \( \theta_0 \) positive value indicates that flip-turns are characterised by two distinct rotations (about y and x axes), while open-turns are complex movements in which rotations follow each other in a faster way.
The use of gyroscopes allowed us to describe, the strategy adopted by each athlete during his/her swimming action, also. This was done using both $\omega$ and $\tau$ parameters. Dealing with stroke rates, $sr_{25}$ was consistently lower than $sr_{50}$, a circumstance that is presumably related to the appearance of fatigue. This parameter was typically lower in females than males, except for butterfly where the female and male swimmers obtained similar $sr$ values. This is due to linear relationship between velocity and stroke frequency: the female butterfly swimmer had a very good performance, thus approaching the execution of the male athlete. Thus, the approach proposed in this paper allowed for the quantification of stroke frequency, but its application to performance analysis needs to be carried out in presence of trials at a constant velocity, where differences could be attributed to a different strategy adopted by the swimmer. Focusing on the ratio between gliding and stroke phases, $r_{50}$ was consistently lower than $r_{25}$, which involves a longer gliding phase after the racing start. Highest $r_{25}$ and $r_{50}$ were found for backstroke and butterfly, consistently with their theoretical style executions.

CONCLUSION

Inertial sensor devices integrating both accelerometers and gyroscopes represent a useful tool for performance evaluation in swimming research. Specifically, using gyroscopes represents a promising measurement technique for coaches to investigate how swim turning, underwater gliding and stroke resumption phases are implemented in the different swimming styles. Strength points of the approach are the simple description and stroke resumption phases are implemented in the different swimming styles. Prospects of this research will involve account the inclusion of further athletes and the definition of further parameter (acceleration peaks, estimation of angles), eventually specific for each swimming styles.

REFERENCES


Influence of Swimming Start Styles on Biomechanics and Angular Momentum

Vantorre, J.¹, Seifert, L.¹, Bideau, B.², Nicolas, G.², Fernandes, R.J.³, Vilas-Boas, J.P.², Chollet, D.¹

¹ C.E.T.A.P.S. EA 3832, Faculty of Sports Sciences, University of Rennes, France
² M2S, University of Rennes 2, France
³ CIFIT2D, Faculty of Sport, University of Porto, Portugal

The aim of this study was to analyze how the start style influences angular momentum. The durations of the block and flight phases, body angles at takeoff and entry, kinetic momentum, kinetics, and 15-m time were assessed. The sample was classified according to start style: the flat start showed significantly lower angular momentum ($H=14.7\pm2.92$ vs. $18.0\pm0.67$ and $17.5\pm0.4$ for pike and Volkov), shorter flight phase and distance, and a smaller takeoff angle than the two other start styles. The analysis of angular momentum revealed two main strategies to achieve optimal performance: direct entry into the water to reduce the temporal deficit and start swimming early (flat start), and the immediate generation of high velocity to achieve longer flight time and distance in order to compensate for the relative loss of time in the following parts of the start (pike and Volkov).

Key words: Swimming start, start style, expertise, angular momentum

INTRODUCTION

Many studies have compared the different positions on the start block, but few have compared the aerial curve (defined as the takeoff and entry angles, and the body angles at takeoff and entry). The flat start and the pike start (also called the scoop, whip or hole start) have been described (e.g., Maglischo, 2003) but only a few studies have compared the two. Counsilman et al. (1988) showed a longer start time, greater takeoff and entry angles, and a shorter distance to head entry for the pike start than for the flat start. However, this study was carried out in young swimmers from 10 to 17 years old and not in elite sprinters. In contrast, Wilson and Marino (1983) showed in elite swimmers a shorter 10-m start time, a greater entry angle, a shorter distance to entry, and a greater hip angle at entry for the pike start than for the flat start. Kirner et al. (1989) had five training sessions for swimmers in which they combined grad/track starts and pike/flat entries and demonstrated that the grad start-flat entry had a shorter 9-m start time and a smaller entry angle than the grad start-pike entry. However, this study did not compare specialists of each start style but instead imposed training in and performance of the four styles; therefore, the 8-m start time may have been influenced by the preferential style of the swimmers. Seifert et al. (in press) studied 11 elite grad starters and front crawl sprint specialists and distinguished four aerial phase profiles. In addition to the flat start (upper limbs almost extended at takeoff and used for impulse in the block phase) and the pike start (greater arm swing and great takeoff and entry angles), they observed two other styles of aerial curve: the Volkov start (shoulders stretched upward and forward instead of arms) and flight start (short block phase but long flight phase due to great leg power).

McLean et al. (2000) calculated the angular momentum of the aerial phase, which is generated during the block phase in order to quantify rotation. They analyzed several start relay techniques, with and without one or two steps before taking off from the block. Taking steps before leaving the block resulted in greater takeoff and entry angles (like a pike start) and each step start was characterized by greater body rotation than the no-step start. Pike trajectory or arm swing during the flight phase (Volkov style) thus has an effect on body rotation and consequently on the aerial part of the start. Indeed, the swim start cannot be reduced to generate the greatest forward impulse; the initial position is a blocked...
The Shapiro-Wilk test), ANOVA tests analyzed the variables that significant different between the three start styles. The Volkov start showed negative values because of the position of the arms behind the trunk. The entry angle was significantly greater for the pike start (34.3±3.9°, 39.7±2.8° and 37.3±1.1°, respectively, for the flat, pike and Volkov starts). Although these differences were not statistically significant, greater entry angles were observed for the pike and Volkov vs. the flat start. No significant difference in performance to the 15-m mark was observed between the start style groups. The takeoff angle, flight distance, and the total and standard deviation of the angular momentum were significantly lower for the flat start than for the other two start styles (with a significantly longer flight phase for the Volkov start in comparison with the two other starts). The time to 15-m was significantly and negatively correlated with the vertical impulse (r=-0.507) and positively correlated with ΔH (r=0.461) (Table 1).

Table 1. Start parameters as a function of start style

<table>
<thead>
<tr>
<th>Start Style</th>
<th>Flat Start (n=5)</th>
<th>Pike Start (n=1)</th>
<th>Volkov Start (n=2)</th>
<th>Correlation with T15m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block Phase (s)</td>
<td>0.95±0.04</td>
<td>0.94±0.03</td>
<td>0.89±0.08</td>
<td></td>
</tr>
<tr>
<td>Flight Phase (s)</td>
<td>0.26±0.02</td>
<td>0.32±0.06</td>
<td>0.38±0.03</td>
<td>a, b</td>
</tr>
<tr>
<td>Flight Distance (m)</td>
<td>3±0.06</td>
<td>3.2±0.01</td>
<td>3.2±0.03</td>
<td>a, b</td>
</tr>
<tr>
<td>Takeoff Angle (°)</td>
<td>22.1±3.5</td>
<td>30±6.0</td>
<td>34.6±5.2</td>
<td>b</td>
</tr>
<tr>
<td>Entry Angle (°)</td>
<td>23.4±2.2</td>
<td>24.6±4.8</td>
<td>28.2±2.5</td>
<td></td>
</tr>
<tr>
<td>Body Angle at 15-m</td>
<td>145.3±7.6</td>
<td>27.1±10.5</td>
<td>-55.4±13.9</td>
<td>a, b</td>
</tr>
<tr>
<td>Horizontal Impulse (N)</td>
<td>788.4±48.7</td>
<td>698.9±60.8</td>
<td>829.2±61.9</td>
<td>a</td>
</tr>
<tr>
<td>Vertical Impulse (N)</td>
<td>188.7±26.2</td>
<td>171.5±21.2</td>
<td>205.4±31</td>
<td>r=-0.507</td>
</tr>
<tr>
<td>H Takeoff (kg/m/s^2)</td>
<td>14.7±2.92</td>
<td>18.0±6.67</td>
<td>17.8±0.4</td>
<td>b</td>
</tr>
<tr>
<td>ΔH (kg/m/s^2)</td>
<td>0.8±0.13</td>
<td>1.1±0.2</td>
<td>1.1±0.15</td>
<td>r=0.461</td>
</tr>
</tbody>
</table>

- a: significantly different from the previous style on the table; b: significantly different from the flat start

### DISCUSSION

The aim of this study was to analyze how the start style influences angular momentum. The results regarding the kinetic momentum showed that significantly less rotation generated during impulsion induced a flat aerial trajectory and permitted the swimmers to enter the water more quickly (as demonstrated by a significantly shorter flight phase). The pike and Volkov starts showed significantly more rotation. The arm swing in the pike (forward) and Volkov (backward then forward) increased the quantity of rotation. In the Volkov start, the backward swing during impulsion accelerated the forward rotation of the body but the swimmer’s head was in complete extension, thus in opposition to the arms. The opposite was observed for the pike start. The body angle at takeoff indicated that the arms were in continuation of the body for the flat start (angle close to 180° with 145.3±7.6°). The Volkov start showed a negative value due to the fact that the arms were behind the trunk, and the values were low for the pike start (27.1±10.5°), indicating that the swimmers were able to swing the arms forward during the flight phase. The takeoff and entry angles, distance to hand entry, and phase duration were in the range of the results provided by the literature: flight distance was 3.09±0.14 m in our study vs. 3.42±0.16 m for McLean et al. (2000), and the angular momentum was 16.2±2.5 kg.m²/s in our study vs. 16.4±3.2 kg.m²/s for McLean et al. (2000). The vertical impulse was significantly and negatively correlated with time to 15-m, indicating that an efficient vertical impulse needs to be high enough to ensure that the flight
distance is sufficiently long (this variable was not significantly different among the start styles). These elite swimmers had flight distances of at least 5 m. The mean standard deviation for the angular momentum was used to determine the transfer of angular momentum from the transverse axis to the two other axes, especially the sagittal axis with twisting of the trunk. The results indicated that the flat start (in grab start technique) induced less angular momentum transfer. The transfer may have been affected in rotations in the sagittal axis (rotations of shoulders and/ or hips), as shown by Benjanuvatra et al. (2004) through the measurement of the dissymmetry in the left and right foot impulses during the grab (and track) start. This dissymmetry can produce a sagittal rotation of the hips and consequent twisting of the trunk. The flat start showed less standard deviation, which indicates that start performances with this style can be as efficient as with the two others. The flat start style in fact indicates that some swimmers prefer to reduce a temporal deficit (lower mastery of the start technique) rather than trying to travel greater distances in the air in order to keep higher velocity at water entry for the following phases.

CONCLUSION
Expertise cannot be reduced to the efficient performance of a single technique. Instead, it is demonstrated by the optimization of personal characteristics in order to achieve optimal performance. These expert swimmers displayed two means to obtain optimal performance: direct (and clean) entry into the water to reduce the temporal deficit and start swimming early, and the immediate generation of high velocity with greater flight distances to compensate for the relative loss of time in the following parts of the start (the glide phase, for example).

REFERENCES


Zatsiorsky, Seluyanov (1983). The mass and inertia characteristics of the main segments of the human body. In Biomechanics VIII, 8, 1152-1159

The Validity and Reliability of a Procedure for Competition Analysis in Swimming Based on Individual Distance Measurements

Veiga, S.1, Cala, A.2, González Frutos, P.1, Navarro, E.1

1 Faculty of Physical Activity and Sport Sciences-INER, Madrid, Spain
2 New Zealand Academy of Sport North Island, Auckland, New Zealand

In swimming, competition analyses have been frequently performed according to three segments of the race, equal for all competitors. However, individual distance measurements during start and turn race segments have been scarcely assessed. The aim of the present study was: 1) to verify the validity and reliability of a 2D-DLT based system for competition analysis in swimming and, 2) to compare it with the commonly used technique. Higher values of accuracy (RMSE=0.05 m) and reliability (CV<1%) were obtained. 95% Limits of agreement revealed differences no longer than one frame (0.04 s) between the two compared procedures. The results showed that the 2D-DLT procedures are valid for competition analysis in swimming and that the differences between 2D-DLT and scaling technique are acceptable.

Key Words: Race analysis, 2D-DLT, accuracy.

INTRODUCTION
Every sport activity can be analyzed from a theoretical point of view trying to find out the important issues to improve performance. In the deterministic model suggested by Hay and Reid (1982), factors influencing the output in a specific sport activity (or performance criterions) are listed following a cause-effect relationship.

In swimming, biomechanical analyses have been frequently performed during competition to measure the performance criterions, according to three different segments in the race: start, swim and turn (Hay and Guimarães, 1983). Traditionally, the scaling technique has been used for this purpose, measuring the time spent to swim each segment. With this procedure, the distance of start and turn phases are equal for every competitor (on regular basis, 15 meter) allowing a comparison between competitors (Thompson et al., 2004).

Due to the use of scaling techniques, some distance variables influencing swimming performance like turn distance (Chow et al., 1984), have been scarcely measured in competition. Technical limitations in measurement systems could also explain the existing lack of publications about the performance criterions in competition according to Hay’s deterministic model. Few studies (Pai et al., 1984; Chatard et al., 2003) measured the individual distance swam during start and turn segments, providing valuable information for performance enhancement.

Considering the use of photogrammetric techniques to measure distances during competition recently reported in other sports (Mallo et al., 2009), the aim of the study was: 1) to check the validity and reliability of a 2D-DLT based system for competition analysis in swimming and 2) to compare it with the commonly used scaling technique.

METHODS
Competition analysis was carried out during II and III Circuit Open Comunidad de Madrid, an international competition organized by Madrid Swimming Federation between July 2007 and July 2008. 128 swimmers participants in A and B Finals of 100 meters events of all four strokes were recorded in a 50x25 meters pool.

Three JVC GY-DV500E video cameras recording at a sampling frequency of 25 Hz were positioned at the stands, 7 m above and 12 m away from the side of the pool; each camera captured a different part of the race: start phase (from start blocks to 15 meter), swim phase (from...
20 to 30 meter) and turn phase (from 35 to 50 meter). All cameras were connected to computers where the images were stored in real time. A light flash connected to the official timing system and captured by the camera filming start phase provided the beginning of the time code.

The same camera system was used for both competition analyses: i) using a linear scale system, vertical lines were overlaid on each camera view defining the beginning and/or end of the race segments during the analysis process; ii) using 2D photogrammetry, computerized analysis of the frames was carried out with software Photo 23D (Cala et al., 2009); and the algorithm with 2D direct linear transformation (2D-DLT) was used (Abdel-Aziz and Karara, 1971).

Forty control points (8 calibration and 32 reconstruction) for each camera were uniformly distributed on the horizontal plane delimitated by the water surface. Control points used for calibration purposes were pool-side building marks while reconstruction points were colored buoys from the floating lanes. Reference lines connecting the near and far sides of the pool were used to place the colored buoys at exactly the appropriate distance.

The accuracy of the 2D-DLT measurement system was assessed reconstructing the position of 32 control points in the field of view of one camera; distance between the control points was also reconstructed. Although these control points used for reconstruction purposes were easily recognized in the image, as the accuracy of the competition analysis depends on how well the competitors can be identified. There is no way to directly evaluate the accuracy of every measurement during competition (Challis, 1995), so sampling of the same action must be repeatedly checked for consistency.

For that purpose, two actions at the beginning and the end of the freestyle turn phase were repeatedly digitalized 30 times by the same experienced observer. The swimmer’s hand entry of the last stroke before the wall represented the beginning of the turn; on the other hand, the mark where the swimmer’s head passes completely the water surface after the underwater swim represented the end of the turn phase. No technical actions other than freestyle turn were assessed since both hand entry or head emersion are used in all four strokes. The digitization process was repeated in each lane of the pool, representing the lane 1 the nearest side in the field of view. Horizontal total distance (m) of the turn phase was obtained using the 2D-DLT measurement system.

Finally, 32 times of each stroke and race segment were measured using the two procedures for competition analysis separately. The variables were identified when swimmer’s head pass every reference as follows: start time = start signal to 15 m mark; turn time = 7.5 m – 7.5 m before and after the wall; swim time = start time – turn time.

Root mean square error (RMSE) (Allard et al., 1995), ratio max-to-RMSE, mean error and absolute error were measured to check the accuracy of the 2D-DLT measurement system. Coefficient of variation (CV) as an index of the absolute reliability (Atkinson and Nevill, 1998) and standard deviation (SD) were used to evaluate the consistency of 30 repeated observations. Finally, the two procedures for swimming competition analysis were compared with the Bland and ALtmann’s 95% limits of agreement (Bland and Altman, 1986); heteroscedasticity was previously checked using a Bland-Altman plot.

### RESULTS

The root mean square error of the 2D-DLT measurement system when reconstructing the position of 32 control points was 0.050 meter, less than 0.5% of control space in x axis. Reconstructing the distance between the control points, the RMSE was 0.046 meter, lower than 1.2% of the total distance. (Table 1)

The consistency in the repeated digitization of the swimmer position during the turn phase is shown in Table 2. Considering the total distance of the turn, differences in the measurements are consistently lower than 1%.

![Table 2: Consistency (m) of digitizing the beginning (hand entry), the end (head emersion) and the total distance of freestyle turn using 2D-DLT procedure. (SD: standard deviation; CV: coefficient of variation)](image)

The limits of agreement between the scaling technique and the 2D-DLT photogrammetry in each segment of the swimming race are shown in Table 3. Maximum systematic differences between procedures occur during freestyle and backstroke turn time (0.05 s), being random error higher in the breaststroke turn.

### DISCUSSION

Application of 2D-DLT technique for analysis of swimming competition shows great accuracy. In comparison to studies analyzing activities with a smaller field of view (Table 4), the 2D-DLT procedures in swimming shows similar accuracy values, with errors reported around 0.05 meter. The only study measuring RMSE with 2D-DLT technique (Challis, 1998) reports similar values corrected to dimensions of the field of view. Even if the errors presented are concerned with easily identifiable points in the image, and not anatomical landmarks, the protocol used provides an appropriate method for assessing the accuracy of the reconstruction technique.

### Table 1: Accuracy (m) of the position and the inter-control points distance reconstruction’s using 2D-DLT procedure.

<table>
<thead>
<tr>
<th></th>
<th>Position</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE (root mean squared error)</td>
<td>0.050</td>
<td>0.046</td>
</tr>
<tr>
<td>Ratio max-rmse</td>
<td>2.064</td>
<td>1.941</td>
</tr>
<tr>
<td>Mean error</td>
<td>0.012</td>
<td>0.028</td>
</tr>
<tr>
<td>Absolute error</td>
<td>0.045</td>
<td>0.031</td>
</tr>
</tbody>
</table>

- **Table 2: Consistency (m) of digitizing (hand entry), the end (head emersion) and the total distance of freestyle turn using 2D-DLT procedure. (SD: standard deviation; CV: coefficient of variation)**

<table>
<thead>
<tr>
<th>Lane</th>
<th>Hand entry (SD)</th>
<th>Head emersion (SD)</th>
<th>Turn distance (SD)</th>
<th>Turn distance (CV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0127</td>
<td>0.0092</td>
<td>0.0155</td>
<td>0.5292%</td>
</tr>
<tr>
<td>2</td>
<td>0.0206</td>
<td>0.0109</td>
<td>0.0208</td>
<td>0.5906%</td>
</tr>
<tr>
<td>3</td>
<td>0.0236</td>
<td>0.0159</td>
<td>0.0243</td>
<td>0.8487%</td>
</tr>
<tr>
<td>4</td>
<td>0.0243</td>
<td>0.0143</td>
<td>0.0274</td>
<td>0.7267%</td>
</tr>
<tr>
<td>5</td>
<td>0.0216</td>
<td>0.0192</td>
<td>0.0313</td>
<td>0.9343%</td>
</tr>
<tr>
<td>6</td>
<td>0.0241</td>
<td>0.0188</td>
<td>0.0255</td>
<td>0.7857%</td>
</tr>
<tr>
<td>7</td>
<td>0.0225</td>
<td>0.0178</td>
<td>0.0272</td>
<td>0.9247%</td>
</tr>
<tr>
<td>8</td>
<td>0.0262</td>
<td>0.0214</td>
<td>0.0343</td>
<td>0.9338%</td>
</tr>
</tbody>
</table>

- **Table 3: 95% limits of agreement (s) between 2D-DLT and scaling technique during competition analysis**

<table>
<thead>
<tr>
<th>Stroke</th>
<th>Start time</th>
<th>Swim time</th>
<th>Turn time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freestyle</td>
<td>0.0062 ± 0.0711</td>
<td>0.0344 ± 0.1231</td>
<td>0.0474 ± 0.1341</td>
</tr>
<tr>
<td>Backstroke</td>
<td>0.0164 ± 0.0860</td>
<td>0.0208 ± 0.1088</td>
<td>0.0474 ± 0.1191</td>
</tr>
<tr>
<td>Breaststroke</td>
<td>0.0164 ± 0.1553</td>
<td>0.0348 ± 0.2074</td>
<td>0.0192 ± 0.2365</td>
</tr>
<tr>
<td>Butterfly</td>
<td>0.0167 ± 0.1223</td>
<td>0.0325 ± 0.2083</td>
<td>0.0128 ± 0.1479</td>
</tr>
</tbody>
</table>

183
Table 4: Accuracy of reconstructing the position in x axis when analyzing different activities with DLT procedures. RMSE corrected to the dimensions of the control space.

<table>
<thead>
<tr>
<th>STUDY</th>
<th>ACTIVITY</th>
<th>PROCEDURE</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lauder et al. (2001)</td>
<td>Swimming</td>
<td>3D Peak Performance</td>
<td>0.15%</td>
</tr>
<tr>
<td>Peyton et al. (2002)</td>
<td>Swimming</td>
<td>3D-DLT</td>
<td>0.154%</td>
</tr>
<tr>
<td>Challis and Kervin (1992)</td>
<td>Laboratory</td>
<td>3D-DLT</td>
<td>0.160%</td>
</tr>
<tr>
<td>Sanders et al. (1998)</td>
<td>Swimming</td>
<td>3D-DLT</td>
<td>0.273%</td>
</tr>
<tr>
<td>Challis et al. (1998)</td>
<td>Vertical jump</td>
<td>2D-DLT</td>
<td>0.3%</td>
</tr>
<tr>
<td>Present study</td>
<td>Swimming</td>
<td>2D-DLT</td>
<td>0.333%</td>
</tr>
<tr>
<td>Cappaert et al. (1995)</td>
<td>Swimming</td>
<td>3D-DLT</td>
<td>0.618%</td>
</tr>
</tbody>
</table>

About the consistency of the digitization process, the identification of body landmarks in swimming competition with 2D-DLT technique shows high levels of intra-rater reliability; even in the farthest side of the pool (lane 8) the coefficient of variation of the measured distances is less than 1%. It is suggested that no corrections are necessary if errors reported are less than 3% of the total distance (Blanksby et al., 2004). Two technical actions successfully tested during the digitization process (hand entry and head emersion) allow multiple possibilities in the measurement of any variable during competition.

Although validity of DLT techniques has been confirmed in the video-analysis of underwater footages in two dimensions (Kwon, 1999) and three dimensions (Sanders et al., 1998), no other studies applied DLT techniques to swimming competition analysis; most of the studies use the scaling technique, superimposing digital lines onto the video playback based on pool-side calibration markings (Thompson et al., 2000); with this procedure the distance of the race segments is equal for every competitor. However, no information relating the validation of such a technique has been previously published.

In this study, the measurement of the traditional race segments with both 2D-DLT and scaling techniques showed systematic differences no longer than a frame of standard-speed video (0.04 s.). Random error, however, rise to 0.20 s. in some strokes (breaststroke and butterfly) where the swimmer’s head moves underwater as part of the swim cycle; during these frames, the identification of the swimmer’s position on the image seems to be difficult. Since the use of 2D-DLT technique is shown as accurate and reliable in this study, the differences with the scaling technique could be acceptable for its practical use in competition analysis. However, precautions must be taken when measurements are made during underwater parts of the race.

CONCLUSION

In summary, the application of 2D-DLT technique to the competition analysis in swimming shows to be highly accurate and reliable. Position of the swimmer and distance swim during race segments can be measured within ±0.05 m, allowing the measurement and comparison of different factors influencing performance in competition. For practical implications, time measurements during the different parts of the race using 2D-DLT can be compared with the traditional scaling technique.

REFERENCES


An Analysis of the Underwater Gliding Motion in Collegiate Competitive Swimmers

Wada, T. 1, Sato, T. 2, Ohishi, K. 3, Tago, T. 4, Izumi, T. 5, Matsu- moto, T. 6, Yamamoto, N. 1, Isaka, T. 1, Shimoyama, Y. 6

1 Kokushikan University, Tokyo, Japan
2 Nippon Sport Science University, Tokyo, Japan
3 Tokushima Bunri University, Sanuki, Japan
4 Japanese Red Cross Hokkaido College of Nursing, Kitami, Japan
5 Ritsumeikan University, Kusatsu, Japan
6 Niigata University of Health and Welfare, Niigata, Japan

The purpose of this study was to analyze the underwater gliding motion in collegiate competitive swimmers. Twelve male collegiate swimmers were monitored with a video camera (SK-2130, SONY, Japan) with a sampling frequency of 60Hz in the sagittal plane to measure the angular displacement of their different joints. A motion analysis system (Frame-DIAS4, DKH, Japan) was used to digitize ten body landmarks. The following results were obtained: the highest speed was maintained during the gliding motion when the knee and the hip joint angles of 180 degrees were maintained from push off from the wall to 0.8sec (1.82m). In addition, swimming speed slowed down when the involuntary movements of flexion-extension in the knee and the hip joints were observed during the gliding motion.

Key words: Motion analysis, Underwater gliding motion, Competitive swimming

INTRODUCTION

In competitive swimming races, the improvement of swimming performance is related not only to the effect of stroking but also to performance of the start and the turn phase. Furthermore, it is important that the momentum created by a swimmer in the forward swimming direction is larger than in the opposite direction.

Passive drag is produced by measuring the force necessary to tow a swimmer through the water at a constant speed with his body in a prone position (Adrian and Cooper 1995). The underwater gliding motion during the start and turn phases are important for the total race time in modern swimming (Matinho et al. 2009). Recently, the development of the swimsuit progressed rapidly. Previous studies suggested that this new model swimsuit had an effect on the body compression and the good streamlined posture (Chatard and Wilson 2008, Mollendorf et al. 2004, Roberts et al. 2003), and could reduce the passive drag during the underwater gliding motion (Chatard and Wilson 2008, Mollendorf et al. 2004). Furthermore, many companies have been developed new product of fabrics. These swimsuits were called “high speed” swimsuits. However, most research done by these companies, focusing on the effects of new fabrics, is not published.

The “high speed” swimsuit were hypothesized to assist maintaining the knee and hip joint angles of 180 degrees, consequently, swimmers could keep a better body position and higher speed during the underwater gliding motion.

The purpose of this study was to analyze the underwater gliding motion in collegiate competitive swimmers and to investigate whether wearing “high speed” swimsuit could maintain the knee and the hip joint angles of 180 degree.

METHODS

Subjects and experimental procedures: Twelve healthy male collegiate swimmers (age 19.4±1.3yrs, height 170.0±5.0cm, body weight 67.0±4.8kg, BMI 23.2±1.5) volunteered to participate in this study. The subjects performed underwater gliding motion as fast as possible after a pushoff from the pool wall. During the underwater phase of gliding motion, the swimmer maintained streamline position (Elipot et al. 2009), and it was directed not to kick it. The head of the subjects were completely submerged during gliding. For each subject, only the fastest gliding motion was analyzed.

The subjects were monitored with an underwater video camera (SK-2130, SONY, Japan, Figure 1) with a sampling frequency of 60Hz in the sagittal plane to measure the angular displacement of their different joints. The underwater area covered by the camera ranged from the start wall to the 5-meter point.

In this study, the subjects were asked to wear two different models of swimsuits: one is made of the conventional fabrics; the other is a newly developed, so-called “high speed” swimsuit (Figure 2 and 3, respectively).

All subjects received a written and verbal explanation of the study and gave their written informed consent for participation. Approval was granted from the institutional human ethics committee and the study was conducted in conformity with the Declaration of Helsinki for medical research involving human subjects.

The “high-speed” swimsuit: The Speedo Fastskin LZR racer (LZR) is a fully bonded swimsuit (Figure 3). Its full-length bonded seams are ultrasonically welded together to eliminate stitching, creating the most low profile silhouette and reducing skin friction drag. The LZR is made from Speedo’s own LZR Pulse material the world’s lightest woven swimsuit fabric. It is highly compressive, water repellent, chlorine resistant and fast drying. The LZR is equipped with original panels of ultra-thin polyurethane membrane, precisely cut by laser, which are embedded into the base LZR Pulse fabric. The LZR Pulse fabric was strategically placed on important parts of the body to create a Hydro Form Compression system that provides an optimum streamlined shape and drag reduction for the swimmer. This system also provides a core stabilizer built to support and hold the athlete (Speedo International Limited 2009). However, these objective data were not published.

Figure 1. The underwater video camera (SK-2130, SONY, Japan)

Figure 2. A conventional fabric swimsuit.
Figure 3. The Speedo Fastskin LZR racer (LZR) swimsuits.

**RESULTS**

Figure 5 indicates the stick picture of a swimmer obtained by means of the motion analysis system. The swimming speed of the subject’s center of gravity wearing a conventional swimsuit decreased when the flexion-extension movement in the knee and the hip joints were performed during underwater gliding motion (a typical example is shown in Figure 6). On the other hand, the swimming velocity of those wearing an LZR swimsuit showed that the highest speed was maintained during the gliding motion when the knee and the hip joint angles of 180 degrees were maintained from the push-off from the wall to 0.8sec (1.82m) (a typical example is shown in Figure 7).

The high-speed swimsuit maintained a streamline in a knee joint and a hip joint of 180 degrees in longer time (Table 1). In addition, duration of the swimming speed of the 90% equivalency of the best swimming speed was significantly longer wearing high-speed swimsuit (Table 2).

![Figure 5](image)

**Figure 5.** The stick picture of a swimmer.

![Figure 4](image)

**Figure 4.** The definition of the joint angular displacement.

![Figure 6](image)

**Figure 6.** Relationship between the joint angle and the velocity for the normal swimsuit. This figure indicates that the knee and hip joints were performed flexion-extension movement from start to 0.8sec (1.2m).

![Figure 7](image)

**Figure 7.** Relationship between the joint angle and the velocity for the high-speed swimsuit. This figure indicates that the knee and hip joints were fixed at 180 degrees from start to 0.8sec (1.2m).

**Table 1.** The comparison high-speed swimsuit and normal swimsuit in angular displacement. (n=12)

<table>
<thead>
<tr>
<th></th>
<th>Normal swimsuit</th>
<th>High-speed swimsuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum hip joint angle (degree)</td>
<td>190.8</td>
<td>188.0</td>
</tr>
<tr>
<td>Minimum hip joint angle (degree)</td>
<td>176.8</td>
<td>176.0</td>
</tr>
<tr>
<td>The difference of maximum - minimum hip joint angle (degree)</td>
<td>13.8</td>
<td>10.0</td>
</tr>
<tr>
<td>Maximum knee joint angle (degree)</td>
<td>181.0</td>
<td>184.2</td>
</tr>
<tr>
<td>Minimum knee joint angle (degree)</td>
<td>166.8</td>
<td>170.5</td>
</tr>
<tr>
<td>The difference of maximum - minimum knee joint angle (degree)</td>
<td>14.3</td>
<td>13.7</td>
</tr>
<tr>
<td>Duration of maintained streamline in hip joint (sec)</td>
<td>0.390</td>
<td>0.356</td>
</tr>
<tr>
<td>Duration of maintained streamline in knee joint (sec)</td>
<td>0.299</td>
<td>0.211</td>
</tr>
</tbody>
</table>

The maintained streamline is time when a knee joint and a hip joint angle were fixed at 180 degrees less than ±5%.

**Table 2.** The comparison high-speed swimsuit and normal swimsuit in velocity and high speed duration. (n=12)

<table>
<thead>
<tr>
<th></th>
<th>Normal swimsuit</th>
<th>High-speed swimsuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum velocity (m/sec)</td>
<td>2.82</td>
<td>2.81</td>
</tr>
<tr>
<td>Minimum velocity (m/sec)</td>
<td>1.38</td>
<td>1.39</td>
</tr>
<tr>
<td>Difference of maximum - minimum velocity (m/sec)</td>
<td>1.44</td>
<td>1.41</td>
</tr>
<tr>
<td>90% velocity (m/sec)</td>
<td>2.54</td>
<td>2.53</td>
</tr>
<tr>
<td>Duration of maintained 90% velocity (sec)</td>
<td>0.164</td>
<td>0.071</td>
</tr>
</tbody>
</table>
DISCUSSION
The main aim of this study was to analyze the underwater gliding motion in collegiate competitive swimmers and investigate whether wearing "high speed" swimsuit could maintain the knee and the hip joint angles of 180 degree. The underwater gliding motion of the swimmer is a significant role in the start and the turn phase. During these phases, reducing underwater resistance force leads to the improvement of the swimming performance.

During the underwater gliding motion, the swimmers have to hold a streamlined posture. This posture directly influences the modification of the hydrodynamic resistance created by the swimmer (Havriluk 2007). Elipot et al. (2009) showed that, to hold a streamlined position, a kinematical synergy of the three principal joints' action is an essential. This synergy is characterized by a combination of the three joints, aiming to stay in the best streamlined position, and to glide longer at high speed. The return to the water surface should rather be initialized by a progressive and synchronize action of the three joints (Elipot et al. 2009).

The result of this study showed that the highest speed was maintained during the gliding motion when the knee and the hip joint angles of 180 degrees were maintained from the start to 0.8sec (Figure 7). In addition, swimming speed slowed down when the involuntary movements of flexion-extension in the knee and the hip joints were observed during the gliding motion. These results suggested that the subjects could not maintain the knee and the hip joint angles of 180 degrees during the gliding motion, as the results, might try to maintain the body balance by the flexion-extension movements in the knee and the hip joints. Moreover, high-speed swimsuit would support maintaining the knee and the hip joint angles of 180 degrees during the gliding motion without the flexion-extension movements in the knee and the hip joints. Therefore, during the underwater phase during starts and turns, it is a necessity that the swimmer maintains a streamlined posture.

CONCLUSION
The highest speed was maintained during the gliding motion when the knee and the hip joint angles of 180 degrees were maintained from push off from the wall to 0.8sec (1.82m). In addition, swimming speed slowed down when the involuntary movements of flexion-extension in the knee and the hip joints were observed during the gliding motion.

REFERENCES

Head Out Swimming in Water Polo: a Comparison with Front Crawl in Young Female Players
Zamparo, P., Falco, S.
Faculty of Exercise and Sport Sciences, University of Verona, Italy

The aim of this study was to measure heart rate (HR), arm stroke efficiency (ηp) and trunk incline (TI) during head out swimming (HOS) and front crawl swimming (FCS) in young female water polo players (12 and 16.5 years of age, 3.3 and 4.8 years of practice, respectively) at different speeds (from slow to maximal). The need of keeping the head out of the water and the elbows high in HOS leads to a small (2%), albeit significant, reduction of the self select speed in comparison to FCS. During HOS the players have a larger (32%) TI while ηp is significantly reduced (21%) than during FCS. Both factors (the increase in TI and the reduction in ηp) lead to an increase of the energy requirement of this peculiar "form of locomotion in water" as confirmed, albeit indirectly, by the higher (10%) observed in HOS at any given speed.

Key words: water polo, arm stroke efficiency, hydrodynamic resistance.

INTRODUCTION
In water polo, dribbling is the technique of moving the ball, while swimming forward, in the wake created by alternating arm strokes. With this technique the players keep the elbows high (in order to stop opposing players from gaining possession of the ball) and keep their head out of the water to see the rest of the pool and make the appropriate play.

This "mode of locomotion in water" is expected to be quite expensive energetically since the need of keeping the head out of the water necessary means that the trunk is more inclined in respect to the horizontal (and this should have an effect on the hydrodynamic resistance, Wp) while keeping the elbows high probably affects the propulsive efficiency of the arm stroke (ηp). Both Wp and ηp are known to affect the energy cost of aquatic locomotion (C, the energy expended to cover one unit distance):

\[ C = \frac{W_p}{\eta_p \eta_m} \] (1)

where ηp is the mechanical efficiency of swimming (e. g. Zamparo et al., 2008). Thus the hypothesized increase in Wp and decrease in ηp should lead to a proportional increase in C, in respect to the condition of a "standard" front crawl stroke.

Whereas in the literature it is reported that water polo players are less economical in front crawl (head down) swimming compared to competitive swimmers (for a review see Smith, 1998) to our knowledge no one has investigated so far the energy cost of swimming during head out swimming nor its determinants: i.e. the efficiency of the arm stroke and/or the hydrodynamic resistance.

Moreover, as well as competitive swimmers learn how to swim efficiently (by improving swimming technique) also water polo players are expected to learn how to swim wit the head out in the most efficient and economical way. We can thus hypothesize that more expert water polo players would show a lower difference between head out swimming (HOS) and front crawl swimming (FCS) than younger, less expert ones.

The aim of this study was, therefore, to investigate the trunk incline and the propelling efficiency of the arm stroke in two groups of young female water polo players (G-12: 12 years old and G-16: 16.5 years old) while swimming both styles (HOS and FCS) at different speeds (from slow to maximal).
METHODS
Twenty-one young female water polo players participated to the study. They were divided into two groups: G-12: 11 players, their average age, stature and body mass were, respectively: 11.9 ± 1.4 years; 1.59 ± 0.07 m; 48.4 ± 5.3 kg; and G-16: 10 players, their average age, stature and body mass were, respectively: 16.5 ± 1.3 years; 1.64 ± 0.04 m; 65.2 ± 9.5 kg. The G-12 players had a practice of water polo of 3.3 ± 0.5 years whereas the G-16 players of 4.8 ± 0.6 years. The subjects were informed about the methods and aims of the study and gave their written informed consent to participate; parental consent was obtained for under age subjects.

The experiments were performed in an indoor 25 m swimming pool. The subjects were requested to swim at constant speed and stroke rate starting, without diving, from the pool wall. The experiments were repeated at 4 speeds (self selected by the swimmers as slow, moderate, fast and maximal) and with the two styles (HOS: head out swimming and FCS: front crawl swimming) in two separate days.

In the central 10 m of the pool the average speed (\( V \), m \( \cdot \) s\(^{-1} \)), the stroke frequency (\( SF \), Hz) and the kick frequency (\( KF \), Hz) were measured by means of a stopwatch. The stroke length (\( SL \), m) was then calculated as \( V/SF \).

The arm stroke efficiency was calculated according to the simple model proposed by Zamparo et al. (2005). The model is based on the assumption that the arm is a rigid segment of length \( l \) rotating at constant angular speed about the shoulder and yields the average efficiency for the underwater phase only, as follows:

\[
\eta_a = \frac{(V \cdot 0.9)}{(2\pi \cdot SF \cdot l)} \quad (2)
\]

where \( V \) is the average speed of the swimmer, \( SF \) is the stroke frequency and \( l \) is the average shoulder to hand distance. In turn, \( l \) can be calculated trigonometrically by measuring the upper limb length (0.49 ± 0.02 m in G-12 and 0.50 ± 0.02 m in G-16) and the average elbow angle (\( ED \)) in the in-sweep of the arm pull. In this study, \( ED \) was not directly measured but calculated on the basis of the subject’s age based on data published by Zamparo (2006). Finally, in equation 7, the speed was multiplied by 0.9 to take into account that, in the front crawl, about 10% of forward propulsion is produced by the legs (e.g. Hollander et al. 1988).

For a detailed discussion about the pros and cons of this model the reader is referred to Zamparo et al. (2005) and Zamparo (2006).

During the experiments video records were taken, with a sampling rate of 50 Hz, by means of a video-camera (TS-6031PSC, CANO- PUS, UK) positioned 0.5 m below the water surface, perpendicular to the swimmer’s direction (the subject swims in the second lane, at a distance of 7-8 m from the camera). After the experiments, the data were downloaded to a PC and analyzed using a commercial software package (Twin pro, SIMI, G). In FCS trunk incline (\( TI \), degrees) was measured from the angle with the horizontal of the segment between the shoulder (acromion) and the hip (great trochanter) whereas in HOS, instead of the shoulder, the margin of the axilla was marked instead (since the shoulder joint is outside the water in this condition). The measurement of \( TI \) was taken, for a single passage, at the end of the in-sweep (when the hand is directly below the shoulder) since in this position the rotation around the sagittal axis is the least and has the smaller influence on the degree of rotation (see also Kendjile et al. 2004).

Finally, the subjects were equipped with a waterproof heart rate monitoring system (RS800sd, Polar, FI) so their heart rate (\( HR \), bpm) at the end of each trial was recorded as well. These data should indicate, albeit indirectly, whether the differences in the kinematical/biomechanical parameters between styles and groups do indeed lead to differences in the energetics of swimming.

Statistical analysis was carried out by means of an ANOVA test (SPSS v17.0, SPSS Inc., Chicago Ill., USA) for repeated measures: two groups (G-12 and G-16), four speeds (V1 – V4) and two conditions (FCS: front crawl swimming and HOS: head out swimming).

RESULTS
In tables 1 and 2 are reported the average ± 1 SD values of all the investigated parameters for the two groups (Table 1: G-12; Table 2: G-16) at the four speeds and in the two conditions (FCS and HOS). In both conditions (HOS and FCS) and for both groups (G-12 and G-16), with increasing speed (from V1: slow to V4: maximal) \( KF \) and \( SF \) increase while \( SL \) and \( \eta_a \) decrease; moreover, with increasing speed \( TT \) decreases while \( HR \) increases (ANOVA, \( F_{(3,57)}^p < 0.001 \) in all cases).

Table 1. Average values ± 1 SD of the investigated parameters for the G-12 group

<table>
<thead>
<tr>
<th>Parameter</th>
<th>G-12 (Hz)</th>
<th>G-16 (Hz)</th>
<th>( SL ) (m)</th>
<th>( SF ) (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>1.00 ± 0.08</td>
<td>1.00 ± 0.12</td>
<td>1.33 ± 0.19</td>
<td>1.37 ± 0.13</td>
</tr>
<tr>
<td>V2</td>
<td>1.12 ± 0.09</td>
<td>1.12 ± 0.18</td>
<td>1.39 ± 0.23</td>
<td>1.43 ± 0.27</td>
</tr>
<tr>
<td>V3</td>
<td>1.25 ± 0.16</td>
<td>1.28 ± 0.25</td>
<td>1.42 ± 0.28</td>
<td>1.47 ± 0.31</td>
</tr>
<tr>
<td>V4</td>
<td>1.38 ± 0.19</td>
<td>1.42 ± 0.31</td>
<td>1.48 ± 0.32</td>
<td>1.54 ± 0.36</td>
</tr>
</tbody>
</table>

The comparison between styles (both groups considered, at all swimming speeds) indicates that all parameters are significantly different in the two conditions (HOS and FCS) (ANOVA, \( F_{(1,19)}^p < 0.05 \) in all cases). Swimming with the head out leads to a small (2%), albeit significant, reduction of the self select speed in comparison to FCS. During HOS, the need of keeping the head out of the water does indeed lead to an increase of dynamic resistance whereas the need of keeping the elbows high does indeed lead to an increase of \( SF \) and this suggests that more relevant differences in the biomechanics of swimming in comparison with FCS. The need of keeping the elbows high does indeed lead to an increase of frontal area and hydrodynamic resistance whereas the need of keeping the elbows high does indeed lead to an increase of \( SF \) and this suggests that these players are not able to reduce the need of keeping the arms high.

Table 2. Average values ± 1 SD of the investigated parameters for the G-16 group

<table>
<thead>
<tr>
<th>Parameter</th>
<th>G-12 (Hz)</th>
<th>G-16 (Hz)</th>
<th>( SL ) (m)</th>
<th>( SF ) (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>1.01 ± 0.12</td>
<td>1.01 ± 0.12</td>
<td>1.33 ± 0.19</td>
<td>1.37 ± 0.13</td>
</tr>
<tr>
<td>V2</td>
<td>1.13 ± 0.09</td>
<td>1.13 ± 0.18</td>
<td>1.37 ± 0.23</td>
<td>1.43 ± 0.27</td>
</tr>
<tr>
<td>V3</td>
<td>1.26 ± 0.11</td>
<td>1.26 ± 0.25</td>
<td>1.42 ± 0.28</td>
<td>1.47 ± 0.31</td>
</tr>
<tr>
<td>V4</td>
<td>1.39 ± 0.13</td>
<td>1.40 ± 0.31</td>
<td>1.48 ± 0.32</td>
<td>1.54 ± 0.36</td>
</tr>
</tbody>
</table>

DISCUSSION
Data reported in this study indicate that HOS is characterized by relevant differences in the biomechanics of swimming in comparison with FCS. The need of keeping the head out of the water does indeed lead to an increase of \( TT \) (and thus to an increase of frontal area and hydrodynamic resistance) whereas the need of keeping the elbows high does indeed lead to an increase of \( SF \) and thus to a reduction of the distance covered per stroke (and of the arm stroke efficiency). Both needs do indeed result, as hypothesized, in an increase of the energy requirement of this peculiar “form of locomotion in water” as confirmed, albeit indirectly, by the higher \( HR \) in HOS than in FCS at any given speed.
Interestingly, $KF$ is lower during HOS than FCS and this suggests that these players are not able to contrast the larger trunk incline with a more frequent/forceful leg kick. Moreover, $KF$ and $TI$ do not change with the years of practice (no differences are observed between the two groups for these two parameters) and this suggests that more experienced swimmers essentially rely on a better arm stroke efficiency to overcome the challenges of this “swimming style”.

CONCLUSIONS
This study suggests that while training young water polo players is necessary to improve as much as possible the efficiency of the arm stroke. Moreover, it indicates the importance to teach them how to perform a continuous and regular leg kick to raise, as much as possible, the trunk towards the horizontal. Furthermore, these data indicate that training practice in water polo has to be less intense and with sufficient pauses to allow for a recovery in $HR$, due to its higher energy requirement in comparison with FCS practice.

REFERENCES


Chapter 3. Physiology and Bioenergetics
Models of Vertical Swimming Abilities in Elite Female Senior Water Polo Players

Dopsaj, M.

University of Belgrade Faculty of Sport and Physical Education, Serbia.

This paper aims to define different models of vertical swimming abilities (VSA) in elite female senior water polo (WP) players with regard to all three energetic systems of swim effort. The study included 30 female WP players, members of the Serbian national senior team. On the basis of raw data obtained through testing (four different test loads: 10, 12, 13.5 and 16 kg) the function of Power-Time equation was calculated for each subject applying the general equation \( y = a \cdot b^x \). All data are presented in absolute terms as Absolute Vertical Swim Abilities Model (ABSvswim), in relative terms as Relative Vertical Swim Abilities Model (RELvswim), and in terms of reached biological capacity as Capacity Vertical Swim Abilities Model (CAPvswim). The raw data were used to define the following models of VSA in female WP players: ABSvswim, \( y = 30.4868x^{-0.2087} \), RELvswim, \( y = 47.8754x^{-0.2127} \), CAPvswim, \( y = 91.9195x^{-0.1846} \), respectively.

Key words: Vertical swimming abilities, water polo, female

INTRODUCTION

Although men's water polo was introduced at the modern Olympic Games in Paris in 1900, it was not until the Sydney Olympics in 2000 that women's water polo became an Olympic sport. This is one of the very reasons why sport research on women's water polo is still scanty.

Previous research has established two basic positions a water polo (WP) player assumes in the water during the game: horizontal and vertical (Platanou, 2009). Available studies covered a variety of methods to assess horizontal swimming abilities in women players (Tan et al., 2009), laboratory tests were applied to define the physiological profile based on women players’ abilities (Radovanovic et al., 2007), there was research into the changes of anthropomorphic and physiological characteristics caused by a year-round training cycle (Marrin & Bampouras, 2008), and both general and specific testing was conducted to compare the methods of assessing women players’ abilities (Bampouras & Marrin, 2009). Although the vertical position is dominant while performing the elements of the ball techniques, dual play, and offensive and defensive tactics (D’Auria & Gabbett, 2008), female players' vertical swimming abilities have yet to be studied comprehensively.

This paper aims to define different models of vertical swimming abilities (VSA) in elite female senior WP players with regard to all three energetic systems of swim effort.

METHODS

The study included 30 female WP players, members of the Serbian national senior team (Age=21.6±3.3 yrs, BH=170.5±5.2 cm, BM=64.9±7.1 kg, training experience=7.7±3.3 yrs). The tests were conducted in the seasons of 2007 and 2008 using the standard procedure (Dopsaj & Thasopoulos, 2006) at the beginning of the national team's preparations for the summer season. On the basis of raw data obtained through testing (four different test loads: 10, 12, 13.5 and 16 kg) the function of the Power-Time equation was calculated for each subject applying the general equation \( y = a \cdot b^x \). All data are presented in absolute terms as Absolute Vertical Swim Abilities Model (ABSvswim) in kg of weight mass, in relative terms as Relative Vertical Swim Abilities Model (RELvswim) in % of weight mass in relation to BM, and in terms of reached biological capacity as Capacity Vertical Swim Abilities Model (CAPvswim) in added weight mass in relation to the \( b \) coefficient (calculated as extra load divided with coefficient \( b \)), which represents the maximal hypothetical working biological capacity load. All data were calculated and presented for the following nine time intervals: 5, 10 and 15 s - anaerobic alactic; 30, 60 and 120 s - anaerobic lactic; and 300, 600 and 1800 s - aerobic, as the time intervals characteristic of estimating the intensity, power and capacity of all three energetic systems (Gastin, 2001). All data underwent the descriptive statistical analysis and mathematical modelling through a method of fitting.

RESULTS

All basic descriptive statistics are shown in Table 1. The raw data were used to define the following models of VSA in female WP players: ABSvswim, \( y = 30.4868x^{-0.2087} \), RELvswim, \( y = 47.8754x^{-0.2127} \), CAPvswim, \( y = 91.9195x^{-0.1846} \), respectively (Figures 1, 2 and 3, respectively).

Table 1. Basic descriptive statistics

<table>
<thead>
<tr>
<th>Model</th>
<th>Time intervals (in s)</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute Vertical Swim Abilities Model</td>
<td>MEAN (kg)</td>
<td>22.12</td>
<td>18.98</td>
<td>17.30</td>
<td>14.82</td>
<td>13.57</td>
<td>11.03</td>
<td>9.17</td>
<td>8.02</td>
<td>6.55</td>
</tr>
<tr>
<td></td>
<td>SD (kg)</td>
<td>5.77</td>
<td>3.87</td>
<td>3.06</td>
<td>2.21</td>
<td>2.02</td>
<td>2.17</td>
<td>2.59</td>
<td>2.89</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>CV %</td>
<td>9.37</td>
<td>11.22</td>
<td>12.10</td>
<td>13.27</td>
<td>13.79</td>
<td>14.64</td>
<td>15.08</td>
<td>15.28</td>
<td>15.49</td>
</tr>
<tr>
<td></td>
<td>SD (% BM)</td>
<td>9.67</td>
<td>6.40</td>
<td>4.96</td>
<td>3.23</td>
<td>2.69</td>
<td>2.64</td>
<td>3.27</td>
<td>3.75</td>
<td>4.38</td>
</tr>
<tr>
<td></td>
<td>CV %</td>
<td>27.79</td>
<td>21.69</td>
<td>18.44</td>
<td>14.08</td>
<td>12.81</td>
<td>15.23</td>
<td>21.21</td>
<td>30.55</td>
<td>43.88</td>
</tr>
<tr>
<td>Capacity Vertical Swim Abilities Model</td>
<td>MEAN (% b)</td>
<td>69.69</td>
<td>60.42</td>
<td>55.69</td>
<td>48.58</td>
<td>44.94</td>
<td>37.42</td>
<td>31.77</td>
<td>28.20</td>
<td>23.54</td>
</tr>
<tr>
<td></td>
<td>SD (% b)</td>
<td>9.37</td>
<td>11.22</td>
<td>12.10</td>
<td>13.27</td>
<td>13.79</td>
<td>14.64</td>
<td>15.08</td>
<td>15.28</td>
<td>15.49</td>
</tr>
<tr>
<td></td>
<td>CV %</td>
<td>13.45</td>
<td>18.56</td>
<td>21.73</td>
<td>27.32</td>
<td>30.68</td>
<td>39.11</td>
<td>47.47</td>
<td>54.19</td>
<td>65.78</td>
</tr>
</tbody>
</table>

Figure 1. Following model of Absolute Vertical Swim Abilities Model (ABSvswim).

Figure 2. Following model of Relative Vertical Swim Abilities Model (RELvswim).

Figure 3. Following model of Capacity Vertical Swim Abilities Model (CAPvswim).
DISCUSSION

The female WP players showed the following VSA: they could sustain the vertical position in water at all the energetic intervals with the average load of 22.32, 18.98, 17.30, 14.82, 13.57, 11.03, 9.17, 8.02 and 6.55 kg, respectively. The values obtained were at the levels of 34.81, 29.53, 26.88, 22.96, 20.99, 16.99, 14.07, 12.27 and 9.98 % of BM, respectively.

With respect to the capacity model, the players showed VSA at the following capacity levels: 69.69, 60.42, 55.69, 48.38, 44.94, 37.42, 31.77, 28.20 and 23.54 % of the hypothetical maximum, respectively.

Previous research has established that female water polo players have great anaerobic capacity and muscular strength of the upper body (peak power - 8.05±0.8 W·kg⁻¹, mean power - 6.5±0.4 W·kg⁻¹), a very high level of aerobic endurance (VO₂ peak - 46.52±7.0 mL·kg⁻¹·min⁻¹) on the arm ergometer tests, (VO₂ peak - 61.8±11.9 mL·kg⁻¹·min⁻¹) on the leg ergometer tests, and high values of lung function parameters. The great strength of the upper body and pronounced aerobic endurance of the whole organism are dominant characteristics of elite female water polo players. Along with a relatively pronounced body height and a low percentage of fat tissue, these female athletes are very well predisposed for adaptation to great physical demands over the whole match (Radovanovic et al., 2007).

With regard to Time-Motion analysis of international women’s water polo match play, it was established that the average exercise bout duration was 7.4 ± 2.5 s and exercise to rest ratio within play was 1:1.6 ± 0.6. The average pattern of exercise was represented by 64.0 ± 15.3% swimming, 13.1 ± 9.2% contested swimming, 14.0 ± 11.6% wrestling, and 8.9 ± 7.1% holding position. Significant differences existed between the outside and the center players for percentage time swimming, 13.1 ± 9.2% contested swimming, 14.0 ± 11.6% wrestling, and 8.9 ± 7.1% holding position. The great anaerobic capacity and muscular strength of the upper body (peak power - 8.05±0.8 W·kg⁻¹, mean power - 6.5±0.4 W·kg⁻¹), a very high level of aerobic endurance (VO₂ peak - 46.52±7.0 mL·kg⁻¹·min⁻¹) on the arm ergometer tests, (VO₂ peak - 61.8±11.9 mL·kg⁻¹·min⁻¹) on the leg ergometer tests, and high values of lung function parameters. The great strength of the upper body and pronounced aerobic endurance of the whole organism are dominant characteristics of elite female water polo players. Along with a relatively pronounced body height and a low percentage of fat tissue, these female athletes are very well predisposed for adaptation to great physical demands over the whole match (Radovanovic et al., 2007).

When the results of this study on ABS, REL and CAP values were used to calculate the Fatigue index (which is expressed as the extra weight load decline – that is, observed vertical swimming value results reached in 5 s as the peak power abilities minus observed vertical swimming value results reached in 30 s as the minimum power abilities – divided by the time interval in seconds between the peak and the minimum of the observed vertical swimming values, i.e. divided by 25), the following was obtained: FABS = 0.30 %BM, FREL = 0.47 %BM, and FCAP = 0.84 %BM.

The comparison of results in vertical swimming abilities between the present and the previous study (Dopsaj & Thanopoulos, 2006), which nevertheless tested male elite water polo players using the same methodology, the following gender differences can be inferred: a) With regard to absolute test results, the women players were able to sustain the vertical swimming position for the same time intervals (5, 10, 15, 30, 45, 120, 300, 600 and 1800 s) with a lower percentage of additional load of 38.73, 35.81, 38.38, 38.11, 33.88, 37.48, 36.91, 36.32 and 35.22 %, respectively. b) With regard to absolute test results, the women players were able to sustain the vertical swimming position for the same time intervals (5, 10, 15, 30, 45, 120, 300, 600 and 1800 s) with a lower percentage of additional load of 38.73, 35.81, 38.38, 38.11, 33.88, 37.48, 36.91, 36.32 and 35.22 %, respectively. Generally speaking, with regard to absolute additional load values the female players’ abilities were lower (37.06 %) than the male players, i.e. their average abilities comprised 62.94 % of the comparative men’s abilities.

CONCLUSION

For the water polo training plan, consideration needs to be taken of the primary informative sources, i.e. the physiological demands of the game based on the game duration and the different technical and tactical demands during the game according to player position. The resulting models should be used to control the fitness levels, as well as to assist the development of training technology with WP female players.

REFERENCES


Critical Velocity and the Velocity at Maximal Lactate Steady State in Swimming

Espada, M.A., Alves, F.B.

Faculty of Human Kinetics - Technical University of Lisbon, Portugal

The purpose of this study was to compare critical velocity (CV) to the velocity at maximal lactate steady state (MLSSv) in swimming. Eighteen well-trained male swimmers performed a maximal 400 m front crawl to estimate maximal aerobic velocity (V400) and two to three 30-min constant velocity swims in order to directly determine MLSSv; CV, estimated from 200 m and 400 m maximal swims, was highly correlated to MLSSv (r = 0.94 and p < 0.01) and V400 (r = 0.95 and p < 0.01).

However, CV was significantly faster than MLSSv; confirming that this parameter does not represent a steady metabolic rate in long distance swimming. Nevertheless, CV still seems to be a useful tool for aerobic conditioning evaluation, due to the simplicity of its determination.

Keywords: Exercise; Swimming; Maximal Lactate Steady State; Critical Velocity

INTRODUCTION

The maximal tolerated duration of a constant-load high-intensity swimming bout has been shown to be a hyperbolic function of the power (or velocity) of the exercise (Wakayoshi et al., 1992), similarly to other forms of human locomotion (for a review, see Morton, 2006). According to this model, the velocity-duration relationship has an asymptote on the velocity axis, termed the critical velocity (CV) that has been considered as a valid fatigue threshold and a marker of the transition between the heavy and the severe intensity domains (Poole et al., 1988), since it has also been shown to be a close correlate of the highest metabolic rate associated with pulmonary oxygen uptake (VO2), acid-base status and blood lactate concentration that can be sustained for a certain time at a constant level.

The power output or the velocity corresponding to the CV has also been considered as expressing the maximal lactate steady state (MLSS) (discussed in Pringle and Jones, 2002), although this equivalence has not been confirmed in many experimental studies, especially in swimming (Dekerle et al., 2005b).

The MLSS corresponds to the highest workload or velocity that can be maintained over time without a continuous blood lactate accumulation (Billat et al., 2003) and its measurement demands several subsequent constant load tests that have to be performed with different workloads on different days, until it is possible to determine an individual workload intensity above which the rate of lactate production exceeds lactate clearance. However, the number of studies directly assessing this parameter is surprising limited in swimming, due surely to the time-consuming and cumbersome procedures required, when compared to the performance of an incremental graded test for lactate threshold determination.

The purpose of this study was to compare critical velocity (CV), estimated by a two-component model, using 200 m and 400 m maximal swims, to the velocity at maximal lactate steady state (MLSSv) in well-trained swimmers.

METHODS

Eighteen male national and international level competitive swimmers volunteered for this study. They were aged 17.1 ± 2.8 years, with a height of 177.6 ± 5.7 cm, a body mass of 65.8 ± 9.1 kg and 4.8% body fat of 10.1 ± 2.4%. Subjects have trained regularly for at least 6 years and took no drugs or medications during the study. Most of the swimmers were familiar with swimming pool exercise testing procedures. They were informed of the nature of the experiments and gave written consent to participate in this study.

Athletes were instructed to avoid exhausting exercise the day before the tests and to retain their normal nutritional habits. A standardize warm-up of 600 m was completed in every testing session. A maximal 400 m front crawl was performed in order to use the average velocity between 50 m and the 350 m (V400) as an estimate of the maximal aerobic velocity (Lavoie and Leone, 1988).

CV was calculated from the slope of the regression analysis between the averaged velocity of the 400 m trial previously referred to and a 200 m front crawl maximal trial performed for this purpose.

In a first round of testing, six subjects performed 30-min constant velocity swims at 75 and 80% of V400. The physiological impact of these bouts was clearly so low it was decided to continue the study using higher intensities. All eighteen subjects performed, then, in random order, 30-min at constant velocity at 85, 90 and 95% of V400. Split times for each 50 m were determined and used by two investigators positioned at 7.5 m and 17.5 m of the pool to control the athletes swimming pace. The swimmer was asked to maintain the pre-established swim pace as long as possible. The test was interrupted when the swimmer could no longer match the required swimming velocity. Each subject was stopped every 400 m 30 to 45 seconds) for blood sample collection and record of the rate of perceived exertion (MLSSrpe) (6-20 scale).

Maximal lactate steady state blood lactate concentration (MLSSc) was defined as the highest blood lactate concentration that increased by no more than 1 mmol.L-1 during the final 20-min of a 30-min constant workload (Beneke, 2003; Baron et al., 2005). When this criterion was not accomplished, the test was stopped. MLSSv was the intensity associated with MLSS. Tests were conducted at similar times on separate days (1 day of total rest between tests) at a 25 m pool with the water temperature at 28.2º C. No polyurethane suits were used.

Stroke rate (SR) was measured from three stroke cycles taken in the middle of the pool for every 50 m and stroke length (SL) calculated. Blood lactate concentrations were analyzed using a Lactate Pro LT device (Arkay, Kyoto, Japan). A Polar Sport Tester (S410) recorded the heart rate frequency every 5 seconds during all tests. Paired-samples t-test was used to compare CV and MLSSv. Pearson’s linear coefficient was used to test correlations. Statistical significance was accepted at p < 0.05.

RESULTS

Mean and standard deviation of V400, MLSSv, CV and MLSSc are shown in Table 1. MLSSv corresponded to 89.7 ± 1.2% and CV to 94.0 ± 1.5% of V400. Only one swimmer achieved MLSS at 85% of V400. At MLSSc was defined as the highest blood lactate concentration that increased by no more than 1 mmol.L-1 during the final 20-min of a 30-min constant workload (Beneke, 2003; Baron et al., 2005). When this criterion was not accomplished, the test was stopped. MLSSv was the intensity associated with MLSS. Tests were conducted at similar times on separate days (1 day of total rest between tests) at a 25 m pool with the water temperature at 28.2º C. No polyurethane suits were used.

Stroke rate (SR) was measured from three stroke cycles taken in the middle of the pool for every 50 m and stroke length (SL) calculated. Blood lactate concentrations were analyzed using a Lactate Pro LT device (Arkay, Kyoto, Japan). A Polar Sport Tester (S410) recorded the heart rate frequency every 5 seconds during all tests. Paired-samples t-test was used to compare CV and MLSSv. Pearson’s linear coefficient was used to test correlations. Statistical significance was accepted at p < 0.05.

Table 1. Mean and standard deviation of V400, MLSSv, CV and MLSSc.

<table>
<thead>
<tr>
<th>N=18</th>
<th>V400 (m·s-1)</th>
<th>MLSSv (m·s-1)</th>
<th>CV (m·s-1)</th>
<th>MLSSc (mmol·L-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.49 ± 0.07</td>
<td>1.34 ± 0.06</td>
<td>1.40 ± 0.08</td>
<td>5.3 ± 1.6</td>
</tr>
</tbody>
</table>

CV was significantly faster than MLSSv (p < 0.01) and both expressed velocities significantly different from V400 (p < 0.01).
MLSSv and CV were highly correlated \( (r = 0.94; p < 0.01) \). Both were associated with V400 \( (r = 0.97; p < 0.01 \) and \( r = 0.95; p < 0.01 \), respectively). Regression analysis of CV over MLSSv \( (SSE = 0.02 \text{ m·s}^{-1}) \) revealed that the latter can be predicted with reasonable accuracy from the 200 m / 400 m swim trials CV. Stroke cycle parameters were unrelated to performance, MLSSv or CV.

**DISCUSSION**

MLSS was determined employing only two to three attempts of 30-min swims at constant velocity. In a study conducted with ten inter-regional and national swimmers, Baron et al. (2005) indicated that MLSSv corresponded to 86.5 ± 5.5% of V400. Our results (extreme values of 2.6 and 7.8 mmol.L\(^{-1}\)) are consistent with previous studies conducted with well-trained athletes (i.e. Baron et al., 2003) and indicate that it is impossible to link the true MLSS to a fixed lactate concentration.

Dekerle et al. (2005a) found a decrease in stroke length at intensities above MLSS. It has been suggested that this decrease in SL is related to local muscular fatigue and rising of blood lactate concentration. In the present study, SL was maintained constant by all swimmers during the 30-min velocity swims at MLSS, evidencing that athletes were not under increasing metabolic imbalance.

Wakayoshi et al. (1993) found that CV determined by 200 m and 400m trials almost agreed with the exercise intensity at MLSS. Our results confirm the finding of Dekerle et al. (2005b) that CV over estimates MLSSv in swimmers. The use of a 2-parameter model may explain part of the difference between CV and MLSSv, since this model provides higher estimates than the 3-parameter one, thought to be more accurate and closer to the MLSS velocity or power output (Billat et al., 2003; Morton, 2006). Another point is the variation of the swimming energy cost with velocity, tending to produce a faster CV when shorter distances are used (di Prampero et al., 2008). Bishop et al. (1998) showed that the shorter the predictive trials, the greater the slope of the distance-time regression, even in tasks where mechanical efficiency is rather constant throughout the range of intensities used, attributing this effect to the aerobic inertia dependent on the primary phase of the VO\(_2\) on-kinetics. Several studies have confirmed this shift to faster estimated swimming velocities when using shorter distances (Martin and Whyte, 2000; Toubekis et al., 2006; Reis and Alves, 2006; Costa et al., 2009).

In this study, 200 m and 400 m swimming distances in the estimation of CV is recommended. This is mainly due to the usefulness of a simple enough test to be used frequently in training conditions, in spite of being aware that using more trials would improve the accuracy of the calculation (Dekerle et al., 2005b), but also because these distances comply with the physiological requirements of the model (di Prampero, 1999), corresponding to effort durations that lie between limits within which the hyperbolic relationship appears to provide a good characterization of the physiological response.

Exercise durations of less than 1-min would fail, with strong probability, two criteria: the reaching of maximal oxygen consumption (VO\(_{2}\)max) and the exhaustion of the available anaerobic energy. So, distances of 50 m should not be used for the estimation of CV, and it would be cautioned not to use 100 m trials as well, for the same reasons. The inclusion of a longer distance, of 600 to 800 m, would certainly lessen the tendency to overestimate a true steady metabolic rate power output (Bishop et al., 1998) but this would make the testing much more time-consuming and less practical in a day-to-day basis. It is not advisable to include longer distances as well, not only would that increase the variation in energy cost but also would introduce another source of biasing, since the effort would be performed at a lower %VO\(_{2}\)max.

Therefore, it appears that CV in swimmers does not demarcate the transition from heavy to severe exercise and may not provide a direct non-invasive measure of MLSSv. Differences in exercise intensity of this magnitude have substantial effects on performance factors such as time to exhaustion, as well as the physiological demands of continuous exercises. However, our data also indicates that MLSSv could be estimated from CV with enough accuracy to be used as a guidance to exercise prescription.

**CONCLUSION**

Our results confirm that the direct determination of MLSSv remains the most accurate procedure for exercise prescription aiming at aerobic loading.

This study also confirms previous observations that the CV, estimated from two repeated maximal swims, using a two-parameter model approach, overestimates MLSS, corresponding to an intensity of exercise well into the severe domain.

Swimming critical velocity is still a valuable tool to assess training adaptations and could be used as an estimator of the MLSSv.

**REFERENCES**


**ACKNOWLEDGEMENTS**

The first author gratefully acknowledges the ‘Fundação para a Ciência e Tecnologia, Portugal’ (‘The Foundation for Science and Technology’) for their doctoral fellowship award (SFRH/BD/41417/2007).

Modelling the VO₂ Slow Component in Elite Long Distance Swimmers at the Velocity Associated with Lactate Threshold

Hillard, P. 1, 2, Dekerle, J., 2, Nesi, X., 2, Toussaint, J.F. 1, Houel, N. 1, Hausswirth, C. 2

1Département recherche, Fédération Française de Natation, Paris France
2Chelsea School, University of Brighton, England
3Département des Sciences du Sport, INSEP, Paris, France

INTRODUCTION

The lactate threshold has been shown to represent an essential factor of high-level performance in endurance sports (marathon, Nordic skiing, triathlon, cycling; Billat et al., 2001; Mahood et al., 2001). With training, a reduction in blood lactate accumulation for a given intensity would be the result of lower lactate production and/or increased lactate clearance (Billat et al., 2001; Mahood et al., 2001) associated with lower energy cost (Billat et al., 2001).

The oxygen response to constant load exercise can be characterized by three transient phases. Phase I is a rapid early rise in VO₂ (lasting 15-30 s) and represents the circulatory transit delay between the exercising muscle and lungs (Whipp, 1996). Following the phase I response, the phase II rise in VO₂ is best characterized as an exponential function that attains a steady state within 2-3 min. If the intensity of the exercise is performed above the lactate threshold a slowly developing component of increasing VO₂ (termed the slow component of O₂ uptake kinetics) can be observed (Gaesser et Poole, 1996). Continuous exercise performed at the lactate threshold is also thought to reduce the amplitude of the slow component after a period of training (Carter et al., 2000; Gaesser et Poole, 1996; Whipp, 1996). The VO₂ slow component appears to be more frequent among athletes having a high fractional VO₂ at the lactate threshold (Billat, 2001) which is typical of ultra-endurance athletes (Billat et al., 2001; Lucia et al., 1998; Mahood et al., 2001). In high-level long-distance swimmers, it is hypothesized that a long swimming interval induces a greater slow component of VO₂.

METHODS

Seven elite long-distance male swimmers participated in this study. Their performances over a 800-1500, and 5000-meter front crawl test (V800, V1500, V5000) were recorded. They are expressed in percentage of the world record in Table 1.
TABLE 1. Performances during competition events (5000-m, 1500-m, 800-m) expressed in real time and as percent of world record.

<table>
<thead>
<tr>
<th>S#</th>
<th>LP</th>
<th>T5000-m (l/min.s)</th>
<th>T1500-m (min)</th>
<th>1500-m (min)</th>
<th>T-800-m (min)</th>
<th>800-m (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N</td>
<td>55:31</td>
<td>16:25</td>
<td>88.7</td>
<td>8.31</td>
<td>89.7</td>
</tr>
<tr>
<td>2</td>
<td>N</td>
<td>53:57</td>
<td>16:12</td>
<td>89.9</td>
<td>8.17</td>
<td>92.2</td>
</tr>
<tr>
<td>3</td>
<td>N</td>
<td>55:07</td>
<td>16:12</td>
<td>89.9</td>
<td>8.32</td>
<td>89.6</td>
</tr>
<tr>
<td>4</td>
<td>I</td>
<td>53:46</td>
<td>15:51</td>
<td>91.9</td>
<td>8.12</td>
<td>93.1</td>
</tr>
<tr>
<td>5</td>
<td>I</td>
<td>54:37</td>
<td>16:05</td>
<td>90.6</td>
<td>8.28</td>
<td>90.3</td>
</tr>
<tr>
<td>6</td>
<td>I</td>
<td>54:46</td>
<td>16:01</td>
<td>91.1</td>
<td>8.16</td>
<td>92.4</td>
</tr>
<tr>
<td>7</td>
<td>N</td>
<td>55:44</td>
<td>16:08</td>
<td>90.3</td>
<td>8.22</td>
<td>91.3</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td>55:18</td>
<td>16:03</td>
<td>90.3</td>
<td>8.37</td>
<td>91.2</td>
</tr>
<tr>
<td>SE</td>
<td></td>
<td>00.44</td>
<td>00.15</td>
<td>1.1</td>
<td>0.07</td>
<td>1.3</td>
</tr>
</tbody>
</table>

All swimmers completed an incremental test performed to exhaustion. This test was composed of five consecutive 300-m swims separated by 30s of rest. The speed of each increment was determined from the best time performance of each swimmer in a 400-m freestyle event achieved during the month preceding the test. The speed for the first 300m was 30s slower than the best 400-m time: this time was reduced by increments of 5s for each consecutive 300m until the final 300m performed maximally. Swimming speeds were monitored with Aquapacer ‘Solo’ (Challenge and Response, Inverurie, UK) so that each swimmer could match auditory signals with visual markers positioned every 12.5m along the border of the pool. Blood lactate level (expressed in mEq/L) was determined from a fingertip blood sample which was analyzed immediately using a portable lactate analyzer (Lactate Pro, Arkray, Japan).

The interval training session consisted in a 500-m interval set. The speed of each increment was determined from the best time performance of the 500-m achieved during the previous 500m swimming test. The coefficients of variation are displayed in brackets.

Table 2. Individual values of the parameters from the modelling of the VO2 kinetics using the two-component model. Only the VO2 values of first 500-m of IT6x500 has been used for the modeling. The coefficients of variation are displayed in brackets.

RESULTS

Swimming velocity (vL), oxygen uptake (VO2 L), and blood lactate concentration ([La]b) at L were 1.46 ± 0.01 m·sec⁻¹, 352 ± 17.7 mL·kg⁻¹·min⁻¹ and 3.1 ± 1.2 mmol·L⁻¹, respectively. VO2 LT was 86.8 ± 1.7% of VO2 max and [La]b was 96.7 ± 0.5% of [La]b. VO2 peak was 91.1 ± 1.4 m·sec⁻¹ of the 400-m best performance (with diving start, without snorkel and with kick-off turns). VO2 max, HR peak, RPE and [La]b obtained at VO2 peak during the increment test were 68.7 ± 5.2 mL·kg⁻¹·min⁻¹; 196.3 ± 7.3 mm·sec⁻¹, 18.4 ± 3.2 a.u., 6.9 ± 1.4 mmol·L⁻¹, respectively.

The fit was statistically superior for the two-term exponential model compared with the one-term model (r² = 0.62 ± 0.18 vs. 0.52 ± 0.21, P < 0.01). Furthermore, the Cr score was lower for the bi-exponential model indicating a lesser prediction error (Cr = 0.0000000000000000000000000000000001 ± 0.05 ± 0.21, P < 0.01). Mean time during the 500-m swimming test was 352 ± 17 s. All seven subjects displayed a slow component of VO2 during the 500m with recorded values of 401.7 ± 129.9 mLO2·min⁻¹ and 5.69 ± 1.96 mL·min⁻¹·kg⁻¹ (Table 2).

DISCUSSION

One important novel aspect of this study was that during a 500-m long
interval performed at lactate threshold, all seven swimmers exhibited a slow component of VO2 leading to an attainment of 99% of VO2 max.

The present study demonstrated that the two-term exponential model fit performance better than the single-term exponential model when applied to a population of seven elite swimmers swimming at a velocity corresponding to LT (higher determination coefficient and lower CP score). Bell et al. (2001) demonstrated that this method of modeling the VO2 response (two-components model from 20 sec after exercise onset to the end) is more appropriate and accurate than previous methods, even if the description of phase 3 is still unsatisfying and if the physiological basis for fitting an exponential to this phase is still unclear. The determination coefficient, r² = 0.62 ± 0.17 was slightly lower and the coefficients of variation equivalent to those observed in the ecological running setting (Borrani et al., 2001). Using the same estimation method, these authors reported that the coefficient of variation for the amplitude of the slow component A2 was 47.8% with the same VO2 kinetics model during a limited time of running at 100% max. The greater imprecision compared with laboratory studies such as reported by Borrani et al. (2001) who found coefficients of variation below 15% for all parameters of the model except TD1 could be explained by mathematical and methodological differences. The number of data points for breath-by-breath analysis (240 ± 36) would have to be greater to allow for more accurate adjustment of the two-component model with six parameters. Since the bi-exponential model is non-linear, inference is based on asymptotic theory which, as recommended (Wetherill et al., 1986), would require 180 to 300 data points for our study. Another source of variability would be greater variations in exertion in the setting of ecological exercises (running, swimming) compared with laboratory conditions. The fact that our swimmers controlled their velocity using the visual or auditory landmarks probably imposed a certain degree of variability on muscle workload which was expressed by greater VO2 variability. In addition, the turning phases with the imposed hand-turn created a pause in workload and certainly induced a variable VO2 response which would compromise the accuracy of the model using a complex set of parameters (Wetherill et al., 1986).

The slow component recorded in this study (401.7 ± 129.9 mlO2·min⁻¹ and 5.69 ± 1.96 ml·min⁻¹·kg⁻¹) was equal if not greater than those reported in swimming at equivalent if not higher intensity of exercise, but in less trained swimmers (Bentley et al., 2005; Demarie et al., 2003; Fernandez et al., 2003). Demarie et al. (2001) reported values of 239 ± 194 mlO2·min⁻¹ when measured in six elite pentathletes exercising at above critical velocity but below VO2 peak (v = 1.22 ± 0.06 m·sec⁻¹; lim = 375 ± 38). Fernandez et al. (2008) reported values of 274.11 ± 152.83 mlO2·min⁻¹ for a group of 15 elite swimmers performing a test to exhaustion at VO2 max (v = 1.46 ± 0.06 m·sec⁻¹; lim = 260.20 ± 60.73) while Bentley et al. (2005) found a slow component (7.7±3.1 mlO2·min⁻¹·kg⁻¹) only in 5 of the 9 elite swimmers tested, when swimming at a velocity representing 25% of the difference between ventilatory threshold and VO2 max (1.35±0.03 m·sec⁻¹) for 400-m. One study (Lucia et al., 1998) reports a slow component of 130 mlO2·min⁻¹ in 9 professional road cyclists performing a 20-min exercise above ventilatory threshold (~80% VO2 max; [La]b < 3 mmol·l⁻¹). In agreement with the work reported by Carter et al., 2000, the hypothesis of a cause and effect relationship between the slow component and lactate accumulation or lower pH would not appear to be confirmed by our data since our athletes exhibited low serum lactate levels during the IT65'500 sessions (4.1 mmol·l⁻¹) but with high slow component. This finding supports the conclusions of several researches which associate the slow component with changes in fiber type recruitment pattern (Carter et al., 2000; Gaesser et Poole, 1996; Whipp, 1996). Indeed, in the case of muscle fatigue, additional motor units or muscles (possibly less efficient) will be recruited and the VO2 will increase in order to maintain the work rate when power output of recruited motor unit is reduced. It could be hypothesized that in swimming such progressive muscular fatigue induces a reduction in propulsive efficiency requiring a compensatory increase in stroke rate to maintain speed and consequently a delayed increase in oxygen uptake. Moreover high level endurance swimmers are characterized by a strong capacity to reduce muscle lactate accumulation, so allowing them to maintain a high fraction of the VO2 max at speeds corresponding to the lactate threshold. Therefore high ventilatory responses led by the power of the exercise associated to the inspiratory breathing resistance increase due to the breathing in a snorkel contribute certainly to the amplitude of the O2SC. Therefore, the characteristics of the slow component observed in the present study (high amplitude A2, long delay Td2, and low time constant r2) could be attributed by both the specificity of swimming and high-level endurance of the swimmers.

**CONCLUSION**

Elite Long-distance swimmers attained an exceptionally high percent of VO2 max when swimming at the velocity corresponding to lactate threshold, with this velocity being very close to maximal speeds. All of the swimmers tested exhibited great amplitude of the slow component in their VO2 response.

**REFERENCES**


The Impact of Tension in Abdominal and Lumbar Musculature in Swimmers on Ventilatory and Cardiovascular Functions

Henrich, T.W. 1, Pankey, R.B. 2, Soukup, G.J. 1

1 University of the Incarnate Word, San Antonio Texas, USA
2 Texas State University, San Marcos, Texas, USA

Swimming performance is governed by the ability of the body to consume oxygen for energy production for most events, increase the resistance on the propulsive surfaces, and decrease resistance on the non-propulsive surfaces of the body. It has been proposed that the abdominal and erector spinale muscles contract during swimming to decrease form resistance or drag on the swimmer's body to increase speed. The hypothesis is that contracting these muscle groups would negatively impact pulmonary functions and increase oxygen consumption. Significantly lower pulmonary functions and higher resting oxygen consumption were observed while the abdominal and erector spinale muscles were contracted. Contracting the abdominal and erector spinale muscles could cause decrements in crawl stroke swimming performance.

Key Words: Swimming, Ventilation, VO2, Propulsion, Resistance

INTRODUCTION
Pulmonary function does not appear to place a limit on maximal exercise in most physical activities. However, in competitive swimming, the posture and movements required to properly execute the different strokes often impede and the ability of the body to ventilate the lungs and consume oxygen during butterfly, breaststroke and crawl stroke where breathing is restricted to the movement pattern of the arms and legs and the swimmer's face in the water.

In competitive swimming, particularly during the crawl stroke, the position of the head in the water and the sequence within the stroke where the swimmer can breathe places some restrictions on pulmonary ventilation. In spite of these limitations, pulmonary ventilation has not been shown to limit the performances of competitive crawl stroke swimmers (Ingvar, 1974). The pulmonary functions of swimmers have been studied with regularity because some researchers consider the water pressure against the rib cage a challenge to ventilation that results in an adaptation to exercise not shown in other sports. Clanton and Gadek et al. (1987) compared the effects of 12 weeks of inspiratory muscle training, regular aerobic training and 12 weeks of swim training. Significant improvements in the swim training group were noted for vital capacity p < 0.01, functional residual capacity p < 0.0001, and total lung capacity p < 0.0025 when compared to the regular aerobic training group.

Competitive swimmers can have greater total lung capacities than other athletes (Cordain and Tucker, et al. 1990) and greater forced expiratory volume (Courteix and Ober et al. 1997). Armour and Donnelly et al. (1993) compared pulmonary functions of age-matched swimmers and runners. Swimmers had significantly greater total lung capacity, vital capacity, maximal inspiratory capacity and forced vital capacity than runners when the data were normalized for age and body size. Therefore, swimmers' breathing mechanics and lung volumes should not necessarily limit their performances. These findings suggest that swimmers are not limited directly by ventilatory factors and because of either genetic and/or developmental reasons, appear to have better respiratory and pulmonary functions than athletes participating in other sports.

In terms of bioenergetics, swimming performance is determined by the swimmer's ability to expend energy from both aerobic and non-aerobic sources depending on the events in which they compete. Bio-mechanically, the swimmer must increase resistance on the propulsive surfaces of the body like the hands, legs and perhaps the forearms to produce force. Conversely, they must also decrease resistance on the non-propulsive surfaces of the body like the torso, head and hips (Counsilman & Counsilman, 1994). Skinner (2007) suggests that the posture of the body should be optimized while swimming the crawl stroke to decrease form drag and increase speed. This change in posture involves contracting the abdominal muscles to flatten the abdomen, and erector spinale muscles to flatten the lumbar portion of the spinal column, which collectively produce a more streamlined body. This proposed change in posture could interfere with the coordination of movement between the abdominal muscles and the diaphragm, and work in direct opposition to the accessory respiratory muscles limiting the swimmer's ability to ventilate air and consume oxygen. There seems to be no experimental data in the literature that contracting these muscle groups decreases resistance on a swimmer. These muscular contractions are hypothesized to limit the swimmers' ventilatory capacity and increase oxygen consumption during swimming.

METHODS
Prior to initiating a logistically complex study of swimmers in the water, a land-based study was undertaken to determine if contracted muscles would negatively affect pulmonary functions measured in a controlled laboratory setting. Pulmonary functions and resting oxygen consumption were measured under control and experimental conditions. The non-contracted or control condition (NC) involved measurements made with subjects in a standard sitting position. The experimental or contracted condition (CC) involved participants sitting upright in a chair with their abdominal and erector spinale muscles tensed. This condition was documented by holding a measuring tape around the abdominal area and the participants were instructed to maintain a constant circumference. The participants maintained an upright vertical position of the upper body that was documented by using a meter stick placed next to the trunk. The lumbar spine of the participants was flattened against the back of the chair as close as possible according to the recommendations of Skinner (2007) and the USA Swimming Sport Science Department. It is hypothesized that if vital capacity (VC), maximal voluntary ventilation (MVV), forced vital capacity (FVC) and resting oxygen consumption (RVO2) and resting carbon dioxide production (VC02) were altered with the subject's abdominal and erector spinale muscles contracted in a seated posture, then maximal exercise could be impeded by the decreased ventilatory capacity and increased oxygen consumption and place limits on the performance of the competitive crawl stroke swimmer.

Thirteen participants involved in swimming activities (8 males, 5 females) ages 22-60 years of age volunteered for evaluation of their VC, MVV, FVC1, RVO2 and VC02 under the two differing postural conditions NC and CC. Each participant was measured on a Spirometrics Flowmate III Spirometer for pulmonary functions and a metabolic cart for RVO2 and VC02. There were 3 minutes of rest between counter-balanced trials for all measurements. All participants' pulmonary functions were expressed relative to their age, body weight and height and resting RVO2 relative to body weight.

A one-way analysis of variance (ANOVA) was used to compare NC and CC conditions. The Bonferroni correction factor of 0.05/3 were used, which required a p value of less than 0.0167 for the correlated variables of VC, MVV, and FVC1. The variables of RVO2 and VC02 were not significantly correlated and a 0.05 level of significance was used to test these hypotheses. To account for the percent of variance in the dependent variables related to the variance in the independent variable, the Omega Squared statistic was used (Tolson, 1980).

RESULTS
There were significant differences between all evaluations VC, MVV, FVC1, RVO2 and VC02 between EC and CC. An Omega Squared computation showed the amounts of variance in the dependent variables that were accounted for by the variance in the independent variable or CC. Results are reported mean plus or minus standard error.

199
VC measured under NC 5.21 ± .27 liters and was 111% of the predicted volume. The CC was 4.17 ± .26 liters which was 89% of the predicted volume. This difference was significant (F = 6.77, p < .01). For VC the Omega Squared was 0.63 indicating that 62% of the variance was accounted for by the CC.

MVV was 127 ± 12.2 l/min-1 NC conditions and was 109% of the predicted volume while CC conditions elicited a volume of 87.6 ± 9.5 l/min-1 which was 89% of the predicted volume. This difference was significant (F = 6.44, p < .01). The Omega Squared was .62 indicating that 62% of the variance was accounted for by the CC. FVC was 5.0 ± .27 l for NC which was 109% of the predicted volume while CC elicited a volume of 4.1 ± .24 l which was 86.6% of the predicted volume. This difference was significant (F = 7.96, p < .01). The Omega Squared value was .70 indicating that 70% of the variance was accounted for by the CC.

RVO2 for NC was .39 ± .01 l x m⁻¹ x kg⁻¹ and .52 ± .03 l x m⁻¹ x kg⁻¹ for CC. This difference was significant (F = 14.75, p < .01). The Omega Squared was .84 indicating that 84% of the variance was accounted for by the CC. With regard to carbon dioxide production, there was no significant difference in VC02 between NC and CC (p > .10).

**DISCUSSION**

These results demonstrate that contracting muscles to streamline abdominal posture had negative effects on pulmonary functions and caused an increase in energy cost to maintain the posture while seated and not exercising in laboratory conditions. The statistical tests indicate that these differences would occur 99 times out of 100 if the experiment were repeated. The Omega Squared for the VC, MVV and FEV₁ indicate a ranged from a 62% to a 70% chance that the variance in these dependent measures was caused by the CC. However with the V0₂ measurements 84 percent of the variance in the dependent measures was accounted for by the variance in independent measures. The CC produced pulmonary functions at less than predicted values while the NC produced pulmonary functions at greater than predicted values gives an indication that these muscular contractions could be detrimental to performance of crawl stroke swimming.

Karine, and Sarro et al. (2010) found that swimmers ventilation kinetics were dependent on the coordination between the diaphragm and the abdominal muscles. Swimmers better coordination between the motion of the ribs and the thoraco-abdominal volumes compared to other athletes indicating a coordinated action between the abdominal muscles and diaphragm. These authors suggested that swimming practice leads to formation of optimized breathing patterns in competitive swimmers, partially contributing to the larger lung volumes observed in swimmers. These findings provide evidence that the abdominal and erector spinae muscles should not be intentionally contracted during crawl stroke swimming.

This posture is suggested to increase the work of breathing given an increase in oxygen consumption when the abdominal and erector spinae muscles were contracted statically. Harms and Babcock et al. (1997) found that as the work of breathing was artificially increased during exercise that leg muscle blood flow via vasoconstriction was compromised as well as oxygen consumption being decreased by 10% compared to control values. Gomez, and Strongoli et al. (2009) found that when respiratory muscles became fatigued after vigorous exercise of the abdominal muscles there was a significant increase in fatigue of the respiratory muscles. The contraction of the abdominal and erector spinae muscles during exercise seems to cause a disruption of the coordination of respiratory muscles described by Karine and Sarro et al. (2010) and increases the work of breathing causing the decrements in blood flow described by Harms and Babcock et al. (1997).

Toshimasa (2004) found that the ability of the swimmers to roll their body around its longitudinal axis during front-crawl occurred as a result of forces developed by the center of buoyancy and that the buoyant force was the primary source of generating body roll. Restricting the ability of the swimmers’ to fully ventilate their lungs is suggested to decrease the swimmers buoyancy and negatively impact body roll during crawl stroke swimming.

**CONCLUSIONS**

Contracting the abdominal and erector spinae musculature has not been shown to elicit a decrease in form resistance during swimming. In addition, it was demonstrated that the muscle contractions proposed by Skinner (2007) caused decrements in ventilatory function and increases in oxygen consumption even while the participants were seated and at rest. Harms and Babcock et al. (1997) have shown that as the work of breathing increased during exercise decrements in oxygen consumption occurred in the working muscles due to vasoconstriction. These muscle contractions used during the CC caused an increase in oxygen consumption and this oxygen could have only been consumed by the ventilatory muscles. Contraction of the muscles could impair coordination between the diaphragm and abdominal muscles placing a further limit on pulmonary ventilation. Using the tactic of contracting abdominal muscles and erector spinae muscles to reduce form resistance on the body during crawl stroke swimming is not recommended.
REFERENCE


ACKNOWLEDGEMENTS

We would like to thank the reviewers for their detailed and conscientious work during the revision of this manuscript and Jonty Skinner for his dialogue and exchange of ideas.

Relationship between Propelling Efficiency and Swimming Performance in Elite Swimmers.

Huang, Z., Kurobe, K., Nishiwaki, M., Ozawa, G., Tanaka, T., Taguchi, N., Ogita, F.

1National Institute of Fitness and Sports, Kanoya, Japan
2Prefectural University of Kumamoto, Japan

The relationship between propelling efficiency (ep) and swimming performance was investigated for 9 elite swimmers including an Olympic gold medalist and a finalist (age: 23±1 yrs). The ep was calculated as the ratio of the power to overcome drag (Pd) to the total power output (Po) using the MAD system. The swimming performance of each subject was evaluated by the respective average velocity of 50m, 100m, 200m and 400m maximal swimming. The individual ep (71±6%, range: 56 to 80%) values were significantly related to individual swimming performance in 200m and 400m (200m; r=0.72, *P*<0.05, 400m; r=0.80, *P*<0.01), but not to those in 50m and 100m. The results suggest that ep is a more important factor in swimming performance for middle and long-distance event rather than for short-distance events.

**Key words:** propelling efficiency, elite swimmers, swimming performance

INTRODUCTION

Swimming performance is determined by metabolic capacity, drag and propelling efficiency. Propelling efficiency (ep) is defined as the ratio of the power used to overcome drag (Pd) to the total power output (Po) (Toussaint et al., 1988, 1990), and thus a skilled swimmer who has a higher propelling efficiency can use beneficially a larger proportion of the mechanical power to overcome drag when compared to an unskilled swimmer. However, although there are several studies that investigated with respect to the metabolic capacity and drag in elite swimmers, propelling efficiency has not been examined for elite swimmers. Furthermore, the relationship between propelling efficiency and swimming performance in elite swimmers has not been clarified, either. Therefore, this study aimed to determine ep for elite swimmers and to examine the relationship between propelling efficiency and swimming performance in elite swimmers.

METHODS

The subjects were 9 elite Japanese female swimmers who belonged to an inter-college champion team from 2004 to 2008. Two of them were, a gold medalist in Athens Olympic Games and a finalist of Beijing Olympic Games. Their mean (±SD) age, height, and body mass were 23 (±1) years, 1.64 (±0.05) m, and 59.1 (±2.9) kg, respectively. Each subject was well informed of the purpose, protocol, risks, and procedure of this experiment, and voluntarily participated in this study. Throughout the experiment the water temperature was 28.5 degrees Celsius.

The power used to overcome drag (Pd) was measured using a modified system to measure active drag (MAD system) similar to that described by Toussaint et al.(1988) (Figure 1).

**Figure 1.** Schematic side view of system to measure active drag (MAD system) used in this study.
The MAD system allowed the subjects to push-off from fixed pads at each stroke. Hence, power expended in giving the water a kinetic energy change was 0 (Pd=0) as in free swimming, and thus Po=Pd. The 15 push-off pads were fixed 1.30m apart on a 23m horizontal rod 0.75m below the water surface, making continuous swimming over the system possible. At one end of the swimming pool, one rod was connected to a force transducer. The force signal was processed and stored on the hard disk of the notebook computer. Throughout the measurement, the swimmers used their arms only; their legs were supported and fixed together by a small buoy (buoyant force 15.7N) (ARN-100, ARENA).

The force signal was time-integrated, and yielded the average force. The mean swimming velocity was computed from the time needed to cover the distance between the second and fourteenth pads. The power used to overcome drag (Pd) was calculated from the product of the mean drag force and the mean velocity.

For the measurement of propelling efficiency (ep), each subject swam 300m 6 times using front crawl arm stroke only, 3 times using the MAD system, and 3 times in free swimming. The swimming velocities were set at 80%, 85%, and 90% of the average velocity of 400m maximal arm stroke swimming. These velocities were determined by the need to ensure that all exercise was sub-maximal and also that subjects were able to maintain normal swimming technique even at the lowest velocity. During the measurements, subjects were aided to keep a constant swimming velocity by a pacing device consisting of underwater lights that was set at the bottom of swimming pool (SWIMMING PACE MAKE MODEL PMS-103, TAKAGI). All measurements for each subject were made in one day, taking enough rest to prevent the subjects from becoming fatigued.

To determine energy expenditure, steady state oxygen uptake (VO\(_2\)) during the 300m swim was measured by the Douglas bag method. The face mask used for collecting expired gas allowed unhindered movement of the arms during swimming. In an earlier study the "streamlining" of this design was such that there was no measurable increase in drag (Toussaint et al., 1987). The expired gas collection to measure VO\(_2\) was performed while the subject was swimming the final 50m (after at least 5 min from beginning of the trial), by which time VO\(_2\) had reached a steady state. The O\(_2\) and CO\(_2\) fractions in the expired gas were determined by an automatic gas analyzer (Vmax29c, Sensor medics (PVO\(_2\) in W) of free swimming.

Furthermore, the total power output (Po) of the free swimming was calculated from the product of gross efficiency (eg) and energy expenditure (PVO\(_2\) in W) of free swimming.

\[ P_{\text{free}} = P_{\text{V02}} \times e_{\text{g}} \] (Eq.1)

The rate of energy expenditure (PVO\(_2\)) in Watts was calculated from the oxygen uptake (l•min\(^{-1}\), STPD) and RER following the formula of Carby et al., 1987:

\[ P_{\text{V02}} = \frac{4940 \times \text{RER} + 16040}{60} \times \text{VO2} \] (Eq.1)

The rate of energy expenditure (PVO\(_2\)) measured during swimming on the MAD system was related to the total power output (Po), which was equal to Pd, since the push-off was against the fixed pads (Pk=0). Hence, gross efficiency (eg) in this experiment was computed as follows (Toussaint et al., 1990):

\[ e_{\text{g}} = \frac{P_{\text{V02}}}{P_{\text{V02}}} = e_{\text{g}} \] (Eq.2)

The propelling efficiency (ep) was defined as the ratio of the propelling power (used overcome drag, Pd) to the total power output (Po) (Toussaint et al., 1988), therefore, ep was calculated as Pd divided by Po in free swimming at the same velocity.

\[ e_{\text{p}} = \frac{P_{\text{d}}}{P_{\text{o}}} = \frac{P_{\text{d}}}{P_{\text{d}} + P_{\text{k}}} \] (Eq.4)

The time trials of 50m, 100m, 200m and 400m front crawl were performed on different days. Then, the average swimming velocity was computed from each performance time.

**RESULTS**

The swimming performance (average velocity) of each subject is presented in Table 1.

Measurements for ep were taken during free swimming and on the MAD system in a range of matched velocities (range: 1.22 to 1.46 m•s\(^{-1}\)). PVO\(_2\) calculated from the VO\(_2\) data ranged from 388.5 to 917.7W (MAD system), and from 533.1 to 1367.0W (free swim). The power used to overcome drag (Pd) ranged from 40.7 to 76.5W, and the total power output (Po) in free swimming ranged from 54.1 to 103.4W. The mean value of ep calculated by the ratio of Po and PVO\(_2\) was 10±1% (range: 6 to 11%). Finally, knowing the Po in free swimming and Pd as determined on the MAD system at the same velocity, the calculated ep was 71±6% (range: 56 to 80%) (Table 2).

### Table 1. Swimming performance (velocity) of each distance

<table>
<thead>
<tr>
<th>Distance</th>
<th>Mean Velocity (m•s(^{-1}))</th>
<th>50m</th>
<th>100m</th>
<th>200m</th>
<th>400m</th>
</tr>
</thead>
<tbody>
<tr>
<td>50m</td>
<td>1.22</td>
<td>1.71</td>
<td>1.61</td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>100m</td>
<td>1.28</td>
<td>1.71</td>
<td>1.56</td>
<td>1.48</td>
<td></td>
</tr>
<tr>
<td>200m</td>
<td>1.28</td>
<td>1.89</td>
<td>1.47</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>400m</td>
<td>1.33</td>
<td>1.72</td>
<td>1.62</td>
<td>1.56</td>
<td></td>
</tr>
<tr>
<td>S.W.</td>
<td>1.82 (1.70)</td>
<td>1.58</td>
<td>1.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K.W.</td>
<td>1.88 (1.71)</td>
<td>1.56</td>
<td>1.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F.U.</td>
<td>1.89 (1.71)</td>
<td>1.47</td>
<td>1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K.A.</td>
<td>1.82 (1.72)</td>
<td>1.62</td>
<td>1.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.Y.</td>
<td>1.75 (1.64)</td>
<td>1.56</td>
<td>1.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.U.</td>
<td>1.77 (1.67)</td>
<td>1.58</td>
<td>1.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.K.</td>
<td>1.77 (1.62)</td>
<td>1.52</td>
<td>1.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.S.</td>
<td>1.85 (1.75)</td>
<td>1.67</td>
<td>1.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.T.</td>
<td>1.84 (1.73)</td>
<td>1.65</td>
<td>1.56</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The SD value is given in parentheses.
DISCUSSION

In a previous study, it has been reported that the ep for competitive swimmers (61%) is higher than that in triathlon swimmers (44%), suggesting that ep is an important performance determining factor of swimming (Toussaint, 1990). The findings of this study agree with the previous finding, indicating that the ep observed in elite swimmers of this experiment exceeded 70% on average, which is comparably higher than those reported by Toussaint. Actually, the subjects who participated in this experiment seem to be more skilled and higher level competitive swimmers than those in the previous study.

Furthermore, ep in this experiment significantly correlated to middle- and long-distance performance. A swimmer who has a higher propelling efficiency can use beneficially a larger proportion of the available mechanical power to swim forward, which means that the swimmer can swim more economically at any given swimming velocity.

Since total energy expenditure increase with exercise duration, as swimming distance becomes longer, a more economical swimmer should have a great advantage. Supporting our results, Cappaert et al. (1992) have also reported the differences in ep for sprint (48%), middle- (56%), and long-distance swimmers (62%), suggesting ep is a more important factor for long distance swimmers.

On the other hand, ep did not correlate significantly to short distance swimming performance. Ogita et al. (2004) reported that a significant correlation was observed between maximal propulsive power and 50m/100m swimming performance, suggesting that for short distance swimmers, a higher generation of maximal propulsive power would be more important than economical swimming.

Finally, ep would be a more important factor to determine swimming performance for middle and long-distance event rather than for short-distance event.

CONCLUSION

In conclusion, the results of this study suggest that ep is a very important predictor of swimming performance, especially for middle and long-distance events.

REFERENCES


Effect of Increasing Energy Cost on Arm Coordination at Different Exercise Intensities in Elite Sprint Swimmers

Komar, J.1, Lepôtre, P.M.1,2, Alberty, M.1, Van scantre, J.1, Fernandes, R.J.1, Hellard, P.5,6, Chollet, D.1, Seifert, L.1

1 Centre d’Etudes des Transformations des Activités Physiques et Sportives, Faculté des Sciences du Sport, Université de Reims, France
2 Laboratoire de Recherche Adaptations physiologiques à l’exercice et Réadaptation à l’Effort, Faculté des Sciences du Sport, Université de Picardie Jules Verne, Amiens, France
3 Laboratoire d’Etude de Motricité Humaine, EA-3608, Faculté des Sciences du Sport, Université de Lille, France
4 Centre of Research, Education, Innovation and Intervention in Sport, Faculty of Sports, University of Porto, Portugal
5 Département d’Etudes et Recherches, Fédération Française de Natation, Paris, France
6 Laboratoire Vie Sportive, Tradition, Innovation et Intervention, Faculté des Sciences du Sport de Bordeaux 2, France

The purpose of this study was to analyze the changes of the stroking parameters and the coordination induced by the increase of energy cost (C) of aquatic locomotion. Six elite sprint swimmers performed a 6 300-m incremental swimming test. Stroking parameters (stroke rate, SR; stroke length, SL) and arm coordination (measured by index of coordination, IdC) have been calculated from video data and the C by measuring oxygen consumption and blood lactate. Results showed that an increase in C led to significant increases in IdC, SR and a decrease in SL. Linear regression between IdC and C, SR and C and SL and C suggested that a specific C corresponds to the emergence of a specific coordination and SR/SL ratio. The increase of the anaerobic part of C suggested that fatigue could also influence the emergence of motor organization.

Key Words: Motor control, Biomechanics, Swimming, Energy cost

INTRODUCTION

In cyclic activities and especially in swimming, many constraints have been studied through their effects on the inter-limb coordination and stroking parameters (e.g. effect of gender, speed, specialty, expertise and laterality). In order to facilitate his locomotion, the inter-limb coordination in swimming is managed by the swimmer to overcome the resistive forces inherent to the density of water. According to the definition of environmental constraints (i.e. forward resistance which is a function of the swimmer’s hydrodynamic coefficient but mostly of the speed squared required to overcome this resistance), the shifting to a superposition mode is related to the active drag that sprinters must overcome to swim fast. Indeed, above a critical value of speed (1.8 m s⁻¹) and stroke rate (50 stroke.minute⁻¹), only the superposition coordination mode occurred in elite sprinters (Seifert et al. 2007). In swimming, several studies have also shown that the organismic constraints (i.e. gender, stroke specialty and anthropometry) affected the arm coordination in front crawl. Concerning task constraints, several studies have shown a shifting of coordination with increased race pace or when using paddles (Seifert et al., 2007).

In accordance with Sparrow and Newell (1998), we supposed that modifications of coordination emerge in the interest of energy efficiency. If the opposition mode leads to a greater propulsive continuity, in order to theoretically maintain swimming speed, it would be interesting to investigate the effect of energy cost (C) on the adopted aquatic propulsion mode, i.e. catch-up, opposition or superposition (Chollet et al., 2000).

The purpose of this study was to assess the effects of the interaction of both an environmental constraint (increase in speed between sets) and a task constraint (the maintenance of this speed during the 300-m) on the stroking parameters (stroke rate, SR and stroke length, SL) and arm coordination in front crawl. We hypothesized that the motor organization is influenced by the C and that therefore its increase would lead the swimmers to adapt their coordination and stroking parameters.

METHODS

Six French national swimmers, specialists in sprint front crawl performed six consecutive 300-m swims separated by 30-s resting intervals. Individual personal best 400-m freestyle performances recorded within the month preceding the testing period were used to determine the pace of the incremental stages. The pace of the first 300-m was 30-s slower than the time required to swim 300-m at the adjusted 400-m pace. This time was then reduced by 5-s for each consecutive 300-m until the final 300-m.

Aerial and underwater (0.5 m) side-view cameras were superimposed and fixed on the right side of the pool. A calibration frame of 5-m on the horizontal-axis and 2-m on the vertical axis was positioned on the floor of the swimming pool, orthogonally to the external side-view camera, that enabled us to measure the time over a distance of 5-m to obtain the clean speed (v in m s⁻¹). The arm stroke rate (SR in stroke.min⁻¹) was calculated from hand entry at the first stroke to hand entry at the second stroke. SL (m.stroke⁻¹) was calculated from the average speed (v) and SR (stroke.min⁻¹):

\[ SL = \frac{v \times SR}{60} \]  \hspace{1cm} (1)

Arm coordination was quantified using the index of coordination (IdC) (Chollet et al., 2000). The IdC was calculated for two strokes per 50-m taken in the 10-m central part of the pool, then averaged for the 3 laps of 50-m composing the last 150-m to correspond to the analysis of the oxygen uptake. The IdC was expressed as a percentage of complete arm stroke duration.

During exercise, minute ventilation (V̇E), oxygen uptake (VO₂) and carbon dioxide production (VCO₂) were recorded breath-by-breath by the K4b² telemetric gas exchange system (Cosmed, Rome, Italy) using the Standard K4b² valve. The K4b² system was calibrated according to the manufacturer’s instructions before each test. A capillary blood sample was obtained from the finger at rest, and no more than 30-sec after the end of the first five sets and three minutes after the last set and analyzed for blood lactate concentration (lactate Pro LT, Arkay Inc., Kyoto, Japan). The energy cost per unit distance (C, mLO₂.kg⁻¹.m⁻¹) was defined as:

\[ C = \frac{E}{V̇E} \times \frac{1}{v} \]  \hspace{1cm} (2)

where E is the total metabolic energy expenditure (aerobic and anaerobic pathways) expressed in mLO₂.min⁻¹.kg⁻¹ and v is m.min⁻¹, is the swimming speed (di Prampero 1986) at sub-maximal and maximal intensities. The aerobic part of swimming energy cost (C_aer) was estimated from lactate measurements (mLO₂.net measured during the last minute of each swimming stage and its value at rest) and the swimming speed (di Prampero 1986). Anaerobic glycolytic net energy cost (C_anaer) was estimated using blood lactate. Blood lactate measures (mmol) were converted to oxygen equivalent values as 3 mLO₂.kg⁻¹ of bodyweight per mmol of blood lactate. Thus, C, calculated as the sum of C_aer and C_anaer, represented the energy expended to cover one unit of distance while swimming at a given speed and with a given stroke (anaerobic lactic energy sources seems to be neglected, or assumed to be reduced, when evaluating E: for 200-m or more events). Finally, C is given in J.kg⁻¹.m⁻¹ assuming that 1 mLO₂ consumed by the human body yields 20.9 J (Fernandes et al., 2006).

ANOVA and the Tukey Post-hoc test were used to analyse the differences between the different sets. Linear regression tests studied the relationships among the physiological parameters (C), motor organisation (IdC), stroke rate (SR) and stroke length (SL). For all tests, the level of significance was fixed at P<0.05.

RESULTS

The results showed an increase of IdC, SR and C and a decrease of SL throughout the sets (p<0.005). The relationship between SL, SR, IdC
and \(v\) and \(C\) showed a decrease in SL and an increase in \(SR\), \(ILC\) and \(v\) through the different sets (\(p<0.005\)) (Figs. 1 and 2). The increase of \(C\) related to a significant decrease in the aerobic contribution coupled with an increase of the anaerobic contribution of \(C\) (the anaerobic part dropped from 70.7±10.2% at set one to 60.8±7.8% at set six).

\[
\begin{align*}
\text{ILC in J.kg}^{-1}.m^{-1} & \\
\end{align*}
\]

\[
\begin{align*}
\text{SL in J.kg}^{-1}.m^{-1} & \\
\end{align*}
\]

\[
\begin{align*}
\text{SR in stroke.min}^{-1} & \\
\end{align*}
\]

\[
\begin{align*}
\text{v in m.s}^{-1} & \\
\end{align*}
\]

Figure 1. Mean values of the 6 swimmers in each set for Index of Coordination (\(ILC\)) as a function of energy cost (\(C\)).

DISCUSSION

The aim of this study was to examine how the arm coordination and the stroking parameters are influenced by the increase of \(C\) in swimming. The interaction of both the environmental constraint (increase in speed between sets) and task constraint (the maintenance of \(v\)) led to a significant increase of stroke rate and decrease of stroke length. Individual linear regression tests between \(C\) and \(v\) showed a significant positive relationship for a given speed. Moreover, increasing \(ILC\) while increasing \(C\) led the swimmers to change their motor organization. Indeed, the increase of \(C\) led to a significant increase of stroke rate and decrease of stroke length. Individual linear regression tests between \(SR\) and \(C\) and \(SL\) and \(C\) showed a significant positive relationship between \(SR\) and \(C\) for all the swimmers, and a significant negative relationship between \(SL\) and \(C\) only for two swimmers. During a progressive test of 300-m set distance for sprint swimmers.

Figure 2. Mean values of the 6 swimmers in each set for swimming speed (\(v\)), stroke rate (\(SR\)) and stroke length (\(SL\)) as a function of energy cost (\(C\)).

CONCLUSION

The purpose of this study was to examine the effects of the increasing \(C\) on the stroking parameters and the coordination in front crawl. Results showed that swimmers changed their coordination, \(SR\) and \(SL\) with the increase in \(C\). Strong relationships between energy cost and coordination and energy cost and \(SR\) were observed and suggested that energy cost acted as a constraint influencing the emergence of the motor organization. In the future, it could be interesting to be able to assess the energy cost of a given coordination mode for a range of speeds, and this for the three coordination modes. This protocol could help us to validate the hypothesis saying that for a given speed, swimmers freely adopt the energetically most efficient coordination (e.g. as previously shown in the walk-run transition).

REFERENCES


Swimming and Respiratory Muscle Endurance Training: A Case Study

Lemaitre, F., Chavallard, F., Chollet, D.

Centre d’Études des Transformations des Activités Physiques et Sportives (CETAPS, EA3832), France

The aim of this case study was to investigate whether respiratory muscle endurance training (RMET) would increase performance in a long-distance swimmer. An expert long-distance swimmer trained for 10 weeks in a RMET program (30 minutes a day, 5 days a week) plus his usual swim training. Maximal swim time trials, ventilatory function tests, maximal inspiratory and expiratory pressure (MIP and MEP), and respiratory endurance tests (RET) were done. Ventilatory function parameters were not improved post-training, but MIP, MEP, RET and swimming performance were increased (+19%, +33%, +7 minutes; 50 m: -5.4%; 200 m: -7.2% respectively). RMET may be thus a useful technique to improve performance in long-distance swimmers.

Key words: endurance, respiratory muscle, performance

INTRODUCTION

The aim of this case study was to investigate whether respiratory muscle endurance training (RMET) would increase performance in a long-distance swimmer. Immersion in water increases the pressure around the thorax, raising ventilatory constraints both at rest and during physical effort. Until lately, ventilation was not considered to be a limiting factor for sub-maximal or maximal effort. However, it was shown that this ventilatory limitation decreases maximal performance in healthy subjects and athletes (Verges et al. 2007). It was thus suggested that training might delay respiratory muscle fatigue and permit better distribution of blood flow to the working muscles. It has often been observed that swimmers have pulmonary volumes that are greater than both predicted values and those of controls (Doherty et al., 1997). The improved pulmonary volumes in swimmers could be due to swim training per se (Clanton et al., 1987), stronger respiratory muscles (Doherty et al., 1997), alveolar hyperplasia (Armour et al., 1993), or accelerated pulmonary growth (Courteix et al., 1993). Clanton et al. (1987) showed that pulmonary function, endurance and respiratory muscle force were improved after swim training, whereas supplementary RMET did not lead to additional change. Similarly, Wells et al. (2005) showed that swim training alone improved pulmonary function and respiratory muscle force to the same extent as RMT associated with swim training. These findings seemed to be confirmed in a more recent study in high-level swimmers (Mickleborough et al., 2008). Moreover, it was recently reported that the impact on swimming performance seems to be limited (Kilding et al., 2009).

METHODS

An expert long-distance swimmer (21 years, 183 cm, 71 kg) trained for 10 weeks in a RMET program plus his usual swim training. The athlete’s speciality was the 1,500-m event and he was a finalist in the French national championships. His best performance time on this distance was thus expressed as a percentage of the current world record, and was 93.4%. He was not asthmatic and consented to the study requirements. The experimental procedures were conducted in accordance with the Declaration of Helsinki and were approved by the local ethics committee. He was evaluated on two occasions: before (1 week) and just after the RMET program.

Measurements of body mass and skin folds were generally made between 8.00 and 10.00 A.M.; the swimmer presented after training in a fasted state and all anthropometric parameters were measured by the same investigator. Height was measured to the nearest 0.5 cm (Tanita, Tanita Corp., Arlington Heights, IL, USA). Body composition (fat mass: FM) was estimated with the skinfold method of Durnin and Womersley (1974) using a calibrated skinfold calliper (Model HSK-BI, Baty International, West Sussex, UK). Chest expansion was measured at the level of the xiphoid process using a tape measure. The subject was instructed to perform a maximal exhalation [to residual volume (RV)] and then an inhalation to maximum inspiratory capacity (MIC). Chest expansion was calculated as the difference between circumferences at RV and MIC. The CV of test-retest measurements (within the day) at the level of the xiphoid process was 0.7%. Buoyancy was evaluated by measuring the hydrostatic lift (HL), which is the force that enables swimmers to float when they are immersed in forced inspiration. It was measured at the end of a maximal inspiration when the subject was floating. The subject was in the fetal position, facing downward. A lead mass (0.1-1 kg) was placed on the swimmer’s back between the shoulder blades. The load needed to keep the subject just under the water was taken as the HL. For the glide distance measurement, the subject was asked to adopt a prone position with the arms completely extended at the elbows and wrists, to position the upper arms in contact with the sides of the head (one hand on top of the other), to maintain the feet together with the ankles planar flexed, to hold onto the wire, and to hold his breath after a maximal inspiration. For the passive torque time (Tt), which can be defined as the time it takes for the body to pass from horizontal to vertical position, the same researcher maintained the swimmer in the horizontal position until a signal was given by another researcher, who then noted the time it took for the swimmer to get into vertical position. The subject was asked to hold his breath after a maximal inspiration until the test ended. Each time (before and after RMET), three glide and three Tt measures are made in order to calculate and average the glide distance.

Several parameters were measured for the pulmonary function tests: forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), and peak expiratory flow (PEF). For each parameter, the best value was chosen from at least three consecutive maneuvers differing by no more than 5% (Quanjer et al. 1993). All parameters were measured with a Microquark spirometer (Cosmed, Rome, Italy) in the same conditions, with the subject in a sitting position and breathing through the mouthpiece with a nose-clip. The spirometer volume was calibrated twice daily with a 3-L calibrated syringe. The results were corrected to BTPS conditions and compared with predicted values (Quanjer et al. 1993). The maximal inspiratory and expiratory pressures (MIP and MEP) were measured in the sitting position at the end of a normal expiration and inspiration (MEPFRC, MIPFRC) using a small portable mouth pressure meter (ZAN 100 USB, ZAN Messgeräte GmbH, Germany). The subject was verbally encouraged to achieve maximal strength. All maneuvers were repeated at least twice.

The respiratory endurance test (RET) was performed with the SpiroTiger® device. The subject was asked to sustain a given minute ventilation (VE) with a predetermined tidal volume (VT) and respiratory frequency (fR) for as long as possible; that is, until he could no longer sustain either VT or fR despite three consecutive “warnings” by the experimenter. The RMET was performed 30 minutes a day, 5 days a week, with the same specific device (SpiroTiger®) allowing partial re-breathing of CO2 and thus assuring normocapnic hyperpnea. RMET consisted of voluntary normocapnic hyperpnea at a given VT and fR with a duty cycle of 0.5. The Spirotiger® provided breath-by-breath feedback of fR and VT. The size of the re-breathing bag was set at 30-60% of vital capacity, and VE of the first training session was set at 60% of the maximal voluntary ventilation. The swimmer was instructed to increase fR after 25 min of training, if he felt he would not be exhausted by 30 min. If he felt he could not sustain the target for 30 min, he was to decrease the fR. The swimmer was instructed to increase fR from one session to the next by 1-2 breaths/min and was monitored by the experimenter at least once a week to verify compliance.

The swimming performance was evaluated from the 50-m and 200-m time trials (TT50m and TT200m) swum at maximal velocity and in
randomized order. In addition, at rest and 3 minutes after the end of each swim trial, a 5-μL capillary blood sample was drawn from a finger and analyzed (Lactate proTM, LT-1710, Arkray, Inc., Japan). The rates of perceived exertion (RPE, Borg 6–20 scale) were also measured after each swim trial.

RESULTS

The parameters for the long-distance subject are shown in Table 1. Body mass, fat mass, hydrostatic lift, glide distance and torque time were all decreased after the RMET. Chest expansion was also increased. Ventilatory function parameters (FVC, FEV₁, and PEF) were not improved after training, whereas MIP, MEP, the RET and swimming performances increased (+19%, +33%, +12 min.; 50 m: -5.4%; 200 m: -7.2%). The rates of perceived exertion were decreased after the two swim trials (50 m and 200 m). Lactate concentrations were lower after the swim trials (50 m: -0.7 mmol·L⁻¹; 200 m: -4.4 mmol·L⁻¹).

Table 1. Descriptive baseline and post-training characteristics of the long-distance swimmer.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before RMET</th>
<th>After RMET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass (kg)</td>
<td>71.7</td>
<td>68.6</td>
</tr>
<tr>
<td>Fat mass (%)</td>
<td>9.7</td>
<td>8.9</td>
</tr>
<tr>
<td>Chest expansion (cm)</td>
<td>9.0</td>
<td>8.9</td>
</tr>
<tr>
<td>HL (kg)</td>
<td>3.7</td>
<td>2.9</td>
</tr>
<tr>
<td>Glide distance (m)</td>
<td>14.6</td>
<td>13.2</td>
</tr>
<tr>
<td>Torque time (s)</td>
<td>7.4</td>
<td>6.8</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>7.00</td>
<td>7.07</td>
</tr>
<tr>
<td>FEV₁ (L)</td>
<td>5.13</td>
<td>5.56</td>
</tr>
<tr>
<td>PEF (L·s⁻¹)</td>
<td>11.33</td>
<td>11.24</td>
</tr>
<tr>
<td>MIP (kPa)</td>
<td>7.66</td>
<td>9.13</td>
</tr>
<tr>
<td>MEP (kPa)</td>
<td>4.00</td>
<td>5.32</td>
</tr>
<tr>
<td>RET (min)</td>
<td>16</td>
<td>28</td>
</tr>
<tr>
<td>TT50m (s)</td>
<td>28.13</td>
<td>26.69</td>
</tr>
<tr>
<td>TT200m (s)</td>
<td>128.02</td>
<td>119.41</td>
</tr>
<tr>
<td>RPE50m</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>RPE200m</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>La50m (mmol·L⁻¹)</td>
<td>4.1</td>
<td>3.4</td>
</tr>
<tr>
<td>La200m (mmol·L⁻¹)</td>
<td>10.2</td>
<td>5.8</td>
</tr>
</tbody>
</table>

RMET: respiratory muscle endurance training; HL: hydrostatic lift; FVC: forced vital capacity; FEV₁: forced expiratory volume in one second; PEF: peak expiratory flow; MIP and MEP: maximal inspiratory and expiratory pressure; RET: respiratory endurance test; TT: time trial.

DISCUSSION

The main finding was the improved performance in the swim trials after RMET training and the improved endurance, respiratory muscle force and perceived exertion.

The body mass, fat mass, hydrostatic lift, glide distance and torque time were all decreased after the RMET. These results indicated that the swimmer had become thinner during the training period, losing fat mass, which probably reduced his buoyancy and may have modified his glide and Tt. These changes may also have had an impact on performance, especially for the 200 m.

The findings were compared with previous RMET findings in swimmers. Greater changes in our swimmer’s performance for TT200m were found, whereas TT50m has never been tested before (Mickleborough et al., 2008; Kilding et al., 2009). It is difficult to compare a case study with other studies to explain why our performance effect was higher (TT200m), but it is noteworthy that our RMET was longer (10 weeks vs. 6 weeks) and our subject was an expert long-distance swimmer. Long-distance swimmers, who undergo more endurance training than other swimmers, are usually mixed in with other swim specialities (50 m to 400 m).

It is thus difficult to explain the effect of a specific RMET, such as inspiratory muscle training (IMT), which may not be specific enough for a given swim speciality. RMET seems to be more specific for a long-distance swimmer than IMT. This point may explain in part the differences in performance and respiratory muscle force observed in our study. In previous studies, the tendency toward reduced lactate did not always reach statistical significance (Kilding et al., 2009; Romer et al., 2002). The lactate concentration was also more reduced after the 200-m trial and the RET also increase. Decreased respiratory muscle work and/or improved leg blood flow could have reduced anaerobic metabolism in respiratory and/or leg muscles. Thus, the RET and the lactate concentration changes indicate that during swimming the respiratory muscle work was probably decreased, and can in turn improve leg blood flow reducing anaerobic metabolism. Those parameters reinforce the hypothesis of beneficial effects of specific respiratory training for swimmers.

CONCLUSION

The present individual data suggest that RMET has a beneficial effect on swimming performance (50 m and 200 m), although 200-m performance seemed to be more improved. It may be interesting to compare the effects of respiratory training with the respiratory device adapted to the swimming specialty (sprint: force respiratory device vs. long-distance: endurance respiratory device). Respiratory muscle training can therefore be considered a worthwhile ergogenic aid for competitive swimmers.

REFERENCES


It is thus difficult to explain the effect of a specific RMET, such as inspiratory muscle training (IMT), which may not be specific enough for a given swim speciality. RMET seems to be more specific for a long-distance swimmer than IMT. This point may explain in part the differences in performance and respiratory muscle force observed in our study. In previous studies, the tendency toward reduced lactate did not always reach statistical significance (Kilding et al., 2009; Romer et al., 2002). The lactate concentration was also more reduced after the 200-m trial and the RET also increase. Decreased respiratory muscle work and/or improved leg blood flow could have reduced anaerobic metabolism in respiratory and/or leg muscles. Thus, the RET and the lactate concentration changes indicate that during swimming the respiratory muscle work was probably decreased, and can in turn improve leg blood flow reducing anaerobic metabolism. Those parameters reinforce the hypothesis of beneficial effects of specific respiratory training for swimmers.
Heart Rate Responses During Gradually Increasing and Decreasing Exercise in Water

Nishimura, K. 1, Nose, Y. 2, Yoshioka, A. 2, Kawano, H. 3, Ondera, S. 1, Takamoto, N. 1

1 Hiroshima Institute of Technology, Hiroshima, Japan
2 Graduate School of Kawasaki University of Medical Welfare, Kurashiki, Japan
3 Waseda University, Tokorozawa, Japan

The purpose of this study was to determine the heart rate (HR) responses during and after gradually increasing and decreasing exercise in water and on land. Eight healthy Japanese males volunteered for this study. Subjects performed arm cranking exercise (calibration and triangular tests) for 32-min and recovered for 1-minute. HR and cardiac autonomic nervous system activity were continuously measured. The amplitude and phase lags at the top and bottom of the work rate were measured in each cycle. The results were as follows; 1) the HR phase response was shorter in water than on land, but there were no differences in amplitude, 2) reactivation in cardiac parasympathetic nerve was greater in water than on land, but there were no differences in amplitude, 3) the HR phase response was shorter in water than on land, but there were no differences in amplitude, 4) the HR phase response was shorter in water than on land, but there were no differences in amplitude.

Key words: arm cranking exercise, gradually increasing and decreasing exercise, water immersion, heart rate response, recovery after exercise.

INTRODUCTION

In water, humans have different physiological responses than on land due to the influence of the physical characteristics of water, such as water temperature (hydrostatic), water pressure, buoyancy and viscosity. Venous return is greater in water than on land, which causes increased stroke volume and cardiac output, decreased heart rate, and increased cardiac parasympathetic nervous system modulation.

During arm cranking exercise, there are no significant differences of oxygen uptakes between in-water and on-land conditions, despite water immersion-induced bradycardia (Kimura et al., 2001). In addition, the high frequency component in heart rate variability, an index of cardiac autonomic nervous system, is enhanced at the onset of arm cranking exercise in water compared with the on land response. These data suggest that during exercise at the same work-load, heart rate responses including heart rate variability are different between on-land and in-water conditions. Heart rate kinetics (i.e., phase response and amplitude) during sinusoidal exercise are affected by cardiopulmonary fitness (Fukuoka et al., 2002), physical fitness status (Fukuoka et al., 2002) and low intensity aerobic training (Nabekura et al., 2007). In fact, the time delay of heart rate in response to sinusoidal exercise is shorter in highly fit individuals, suggesting that heart rate kinetics in response to sinusoidal exercise may reflect physical fitness. However, the effects of environmental factors, in particular water immersion, on heart rate kinetics in response to gradually increased and decreased exercise workload, such as in sinusoidal or gradually increasing and decreasing exercise, are largely unknown.

It has been shown that the time constant of heart rate decline for the first 30 second (T30) after exercise can serve as a specific index to assess post-exercise reactivation of cardiac parasympathetic nerve activity (Imai et al., 1994). Nishimura et al. suggested that supine floating after exercise induced a greater activation in the cardiac parasympathetic nervous system, via increase of central venous pressure and cardiac output, and the subsequent arterial baroreflex response caused by greater venous return, leading to bradycardia (Nishimura et al., 2006).

Therefore, it was hypothesized that 1) the phase response and amplitude of heart rate during gradually increasing and decreasing arm cranking exercise in water exercise is higher than on land, and 2) the activation of the cardiac parasympathetic nervous system after exercise in the water is greater than after on-land exercise. To test these hypotheses, the present study was designed to determine the effects of heart rate response during and after gradually increasing and decreasing arm cranking exercise in the water and on land.

METHODS

Eight healthy Japanese males volunteered for this study. Their mean ± SD age, height, body weight, and % body fat were 20.9 ± 0.6 years, 175.3 ± 4.2 cm, 66.9 ± 4.7 kg, and 13.9 ± 2.8 %, respectively. All subjects signed an informed consent form prior to participation in this study.

Subjects performed arm cranking exercise for 32-minutes and recovered for 1-minute in a standing position. Subjects performed two types of exercise, a calibration test and a triangular test. The calibration test consisted of three 4-minute bouts of exercise at 20, 60 and 40% of peak oxygen uptake (VO2peak) with a total duration of 12-minutes. The triangular test consisted of 4-minute bouts of gradually increasing and decreasing work load exercise between 20 and 60%VO2peak for 20-minutes. Both experimental tests were performed on land (L-condition) and in water (W-condition). Water temperature was 30°C and water level was at the height of the iliac crest.

Heart rate and cardiac autonomic nervous system activity were continuously measured under both conditions. Heart rate maximal and minimal values, amplitude (difference between maximal and minimal values), and phase lags at the top and bottom of the work rate were measured in each exercise cycle. The cardiac autonomic nervous system activity was calculated using the Maximum Entropy Calculation (MemCalc) methodology. The heart rate variability frequency domain spectrum was divided into two parts; high frequency (HF; 0.15-0.40 Hz) and low frequency (LF; 0.04-0.15 Hz). The cardiac autonomic nervous system activity was transformed into natural logarithmic values to obtain a statistically normal distribution. The natural logarithm of HF was taken as an index of cardiac parasympathetic nervous system modulation. T30 reected reactivation of cardiac parasympathetic was calculated by decrease of heart rate calculated from RR intervals 30 seconds after exercise. All experiments were performed at the same time. All subjects fasted during three hours prior to the experiments, and caffeine intake was not allowed either during that time. Room temperature and humidity were 27.3 ± 1.2°C and 64.9 ± 5.0%, respectively.

All data are expressed as mean ± standard deviation. Two-way analysis of variance for repeated measurements (condition × time course) and paired t-tests were used to compare values obtained during the L-condition and the W-condition trials. The level of significance was set up at p < 0.05.

Table 1. Changes in heart rate during each work load both in the W-condition and on the L-condition.

<table>
<thead>
<tr>
<th>work load (watt)</th>
<th>L-condition (bpm)</th>
<th>W-condition (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest on land</td>
<td>59.3 ± 7.8</td>
<td>57.0 ± 13.5</td>
</tr>
<tr>
<td>Calibration 20</td>
<td>93.0 ± 7.0</td>
<td>84.3 ± 9.4</td>
</tr>
<tr>
<td>Calibration 60</td>
<td>129.1 ± 13.8</td>
<td>119.2 ± 16.2</td>
</tr>
<tr>
<td>Calibration 40</td>
<td>115.8 ± 15.6</td>
<td>102.7 ± 14.5</td>
</tr>
<tr>
<td>Increasing 40</td>
<td>114.7 ± 16.1</td>
<td>99.6 ± 14.5</td>
</tr>
<tr>
<td>Increasing 45</td>
<td>117.8 ± 14.9</td>
<td>102.2 ± 15.5</td>
</tr>
<tr>
<td>Increasing 50</td>
<td>120.7 ± 14.9</td>
<td>104.9 ± 15.0</td>
</tr>
<tr>
<td>Increasing 55</td>
<td>123.9 ± 15.1</td>
<td>108.1 ± 15.3</td>
</tr>
<tr>
<td>Increasing 60</td>
<td>128.1 ± 14.4</td>
<td>110.8 ± 15.3</td>
</tr>
<tr>
<td>Decreasing 55</td>
<td>130.6 ± 15.3</td>
<td>112.6 ± 15.3</td>
</tr>
</tbody>
</table>
**Table 1**

<table>
<thead>
<tr>
<th>Work Load (watt)</th>
<th>L-condition (bpm)</th>
<th>W-condition (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreasing 50</td>
<td>130.4±16.8</td>
<td>112.4±15.4</td>
</tr>
<tr>
<td>Decreasing 45</td>
<td>129.5±18.1</td>
<td>110.9±15.7</td>
</tr>
<tr>
<td>Decreasing 40</td>
<td>126.7±19.2</td>
<td>108.8±15.8</td>
</tr>
<tr>
<td>Decreasing 35</td>
<td>123.0±19.4</td>
<td>105.2±15.7</td>
</tr>
<tr>
<td>Decreasing 30</td>
<td>120.0±19.1</td>
<td>101.7±15.7</td>
</tr>
<tr>
<td>Decreasing 25</td>
<td>115.8±18.6</td>
<td>98.4±15.6</td>
</tr>
<tr>
<td>Decreasing 20</td>
<td>112.5±18.3</td>
<td>96.0±14.9</td>
</tr>
<tr>
<td>Increasing 25</td>
<td>111.7±17.0</td>
<td>94.7±14.8</td>
</tr>
<tr>
<td>Increasing 30</td>
<td>112.2±16.3</td>
<td>95.5±14.9</td>
</tr>
<tr>
<td>Increasing 35</td>
<td>113.2±16.5</td>
<td>97.4±14.5</td>
</tr>
<tr>
<td>Increasing 40</td>
<td>115.1±16.4</td>
<td>98.7±14.5</td>
</tr>
</tbody>
</table>

ANOVA: *p < 0.05, * *p < 0.05 L-condition vs W-condition

**Figure 1**

The phase lags to (top) the top of the work rate and (bottom) the bottom of the work rate both in the W-condition and on the L-condition.

**Figure 2**

The amplitude of heart rate both conditions.

**Figure 3**

The ln HF under arm caking exercise both conditions.

**Figure 4**

Comparison of T30 in both conditions.

**Figure 5**

The ln HF both condition during 1-minute after exercise.
RESULTS

Table 1 shows changes in heart rate during arm cranking exercise during gradually increasing and decreasing workload. During the calibration test (20, 60 and 40% VO2peak), heart rate in the W-condition was significantly lower than on the L-condition (p < 0.05, respectively). Heart rate in the W-condition was significantly lower than in the L-condition during triangular exercise (ANOVA; p < 0.05). Figure 1 shows the mean response time of heart rate (phase lags) to (a) the top of the work rate and (b) the bottom of the work rate in both conditions. The phase lags to the top the work rate in the W-condition was significantly shorter than on the L-condition (p < 0.05). Furthermore, phase lags to the bottom of the work rate in the W-condition were significantly shorter than on the L-condition (p < 0.05). The amplitude (difference between maximal and minimal values) was no significant different in each condition (Figure 2). The ln HF in the W-condition was significantly higher than on the L-condition during triangular exercise (p < 0.05) (Figure 3). Figure 4 shows T30 in both conditions. T30 in the W-condition was significantly lower than on the L-condition (p < 0.05). During 1 minute after exercise, the ln HF in the W-condition was significantly higher than on the L-condition (p < 0.05) (figure 5).

DISCUSSION

The results of the present study are as follows; 1) the heart rate phase response to gradually increasing and decreasing arm cranking exercise was shorter in the water than on land, but no differences in heart rate amplitude were observed, 2) the reactivation in cardiac parasympathetic tone after arm cranking exercise was greater in water than on land. These results may expand our understanding of heart rate responses modulated by the autonomic nervous system to gradually increasing and decreasing exercise in water.

In the present study, heart rate in water exercise was significantly reduced as compared to land exercise. This fact may depend on immersion-induced bradycardia, and be caused by increased venous return due to water pressure. It is thought that the heart rate response to exercise under the anaerobic threshold level is mainly due to the attenuation of cardiac parasympathetic nervous activity (Xenakis et al., 1975). In the present study, since peak heart rate values in W-condition and L-condition were 113 bpm and 131 bpm, respectively, it is speculated that exercise intensity was below the anaerobic threshold level. Thereby, heart rate response to gradually increasing and decreasing exercise can be also explained by activation of the cardiac parasympathetic nervous system. Indeed, the ln HF (an index of cardiac parasympathetic nerve activity) was higher in the W-condition as compared with on the L-condition, supporting our speculation.

Sone et al. (1997) have suggested that the contribution of the withdrawal of cardiac parasympathetic activity to the increase in heart rate with increasing exercise intensity was greater at lower heart rate, and that the cardiac parasympathetic system was more activated during heart rate decreases than during heart rate increases at the same heart rate. The density of the high frequency spectrum of heart rate during light work rates is higher than during heavier workloads (Nabekura et al., 2007). In this present study, the phase lags at the top and bottom of the work rate in the W-condition were significantly shorter than in the L-condition, suggesting that immersion-induced bradycardia might have caused an increase in the phase lags at the top and bottom of the work rate.

In the present study, T30 in W-condition was greater than in L-condition suggesting that the cardiac parasympathetic nervous system rapidly reactivates in the water. It has been reported that an increase of central blood volume due to water immersion might accelerate the recovery process of cardio-respiratory system (Miyamoto et al., 2001). Given this, the increased venous return shown in the present investigation may contribute to the rapid reactivation of the cardiac parasympathetic nervous system. In fact, the ln HF in the W-condition was significantly higher than in the L-condition 1 minute after exercise.

CONCLUSION

The results of the present study suggest that the activation of the cardiac parasympathetic nervous system caused by water immersion may produce an attenuation of heart rate time response to gradually increasing and decreasing exercise. This attenuation of the phase lags during exercise in the water may contribute to a reactivation of cardiac parasympathetic nervous system after exercise. Thus, exercise and recovery in water may enhance the stability of the autonomic nervous activity not only during exercise but also after exercise.

REFERENCES


Effects of Recently Developed Swimwear on Drag During Front Crawl Swimming

Ogita, F., Huang, Z., Kurobe, K., Ozawa, G., Taguchi, T., Tanaka, T.

National Institute of Fitness and Sports, Japan

The effect on active drag of 3 new types of swimwear compared to conventional wear was investigated in 8 male subjects swimming at different velocities to establish the drag-velocity relationship. The active drag force was directly measured during front crawl swimming using a system of underwater push-off pads instrumented with a force transducer. When mean drag values were estimated for a range of swimming speed (1.2 to 1.8 m s⁻¹), statistically non-significant drag reduction effects of 1-5 N (2-6%) were observed for the new types of swimwear. Even if no major differences in drag were found among swimwear, our results suggest that the observed reduction, even if non significant, could indeed explain the observed competitive advantage.

Key words: active drag, swimwear, MAD system, swimming performance

INTRODUCTION

Recently (2008-2009), numerous new world records were made in competitive swimming. The great success has been considered to be in part attributed to a reduction in drag associated with advances in the quality of swimwear.

Drag consists of skin friction, pressure drag, and wave-making resistance, and total drag equals to the sum of those factors (Toussaint et al., 2000). Previously, it was assumed that friction drag was negligible (5% of total drag) given the high Reynolds numbers (>105) that occur during swimming (Toussaint et al., 1988b). However, later Waring (1999) suggested that a significant reduction in total drag could be accomplished by reducing pressure drag by the use of vortex generators minimizing separated flow.

Over the last decade, swimwear manufacturers have tried further development of special fabrics and surface treatments of swimwear which supposedly reduce drag. The manufacturer which has developed the swimwear used by the most swimmers in the Beijing Olympics claimed that swimmers can reduce (passive) drag by 10% when wearing the new type of swimwear. However, it is probably incorrect to assume that results obtained by passive measurement are directly applicable to those by active measurement (Toussaint et al., 2000). Therefore, in the present study, the total active drag obtained when wearing new types of swimwear were compared to those evoked when wearing conventional swimwear.

METHODS

Subjects: The subjects were 8 well-trained male college swimmers. Their mean (±SD) age, height, body mass, and maximal oxygen uptake (VO₂ max) were 20(±1) yrs, 1.68 (±0.04) m, 64.0 (±5.2) kg, 4.17(±0.36) l min⁻¹, and 65.8 (±4.7) ml kg⁻¹ min⁻¹, respectively. Each subject was fully informed of the purposes, protocol, and procedures of the experiment, and any risks, and voluntarily participated in this study.

Swimwear: To evaluate the effects of differences in swimwear on total drag, a conventional swimwear (box type: A) and 3 new types of swimwear (long type: B, C, D) which was developed in 2008 were used in this experiment (see Figure 1). When mean drag values were estimated for a range of swimming speed (1.2 to 1.8 m s⁻¹), statistically non-significant drag reduction effects of 1-5 N (2-6%) were observed for the new types of swimwear. Even if no major differences in drag were found among swimwear, our results suggest that the observed reduction, even if non significant, could indeed explain the observed competitive advantage.

Measurement of active drag: The measurements were performed with a modified MAD system similar to that described by Toussaint et al. (1988b) (Figure 2). The essential aspects of the apparatus and the accuracy of the collected data have been previously described in detail (Ogita et al., 2004, 2006, Toussaint et al., 1988b). The system allowed the swimmer to push off from fixed pads at each stroke. The 15 push-off pads were fixed 1.30 m apart on a 23 m horizontal rod, and the rod was mounted 0.75 m below the water surface. The rod was instrumented with a force transducer at one end of the swimming pool to measure the push-off forces. The force signal was low-pass filtered (30-Hz cut-off frequency), on-line digitized at 100-Hz sampling rate, and stored on the hard disk of the notebook computer. The force signal pushed off from the second to the last (15th) pad was time integrated, and yielded the average force. The mean velocity was computed from the time taken to cover the distance between the second and last pad (i.e. 13.1 x 1.3 = 16.9 m). For the drag measurement, the subject performed only arm stroke (without leg kicking), and the legs were supported and fixed together by the same pull buoy (buoyant force 15.7 N).

To measure drag and to establish the relationship between drag and swimming velocity, the subjects were asked to swim 25 m more than 10 times at different but constant velocities (range 0.80-1.90 m s⁻¹). At constant swimming velocity the mean propulsive force is equal to the mean drag force (Fd) (Toussaint 1988b). On each trial, mean Fd and mean swimming velocity (v) were calculated. These v and Fd data were least-squares fitted to the function:

\[ F_d = A v^n \]

where, A and n are constants of proportionality, and were respectively adopted as drag coefficient and drag exponent in this study.

All subjects used the same 4 types of swimwear (i.e. one conventional and 3 new, developed in 2008), and the order of testing of each swimwear was randomized. All measurements for each subject were completed in the same day.

Evaluation of effect on drag: The A and n obtained with each swimwear were computed for each subject. These fitted functions were used to estimate the drag at three different velocities (1.2, 1.5, 1.8 m s⁻¹). The effect on drag was evaluated by comparing the estimated drag among 4 types of swimwear. Intra-individual differences (in %) with respect to the drag when wearing conventional swimwear were also calculated at the three velocities studied.

Statistics: All data were expressed by mean and SD or individual value. Two-way analysis of variance with repeated measures was used to test the difference in estimated drag values among 4 conditions by...
swimwear condition and velocity. Also one-way analysis of variance with repeated measures was used to test the difference in A and n among swimwear conditions. When interactions reached statistical significance, then Scheffe's post-hoc test was used to identify the difference in mean values among swimwear conditions. The 0.05 level of significant was used.

RESULTS
In Figure 3, the drag curves (group average) are presented. The drag curves when wearing new types of swimwear were slightly lower than that when wearing conventional swimwear, but no difference in drag was observed among new types of swimwear. Statistics of the fitted curves for all subjects are presented in Table 1. From the fitted curves, estimations were made for the drag at velocities of 1.2, 1.5, and 1.8 m•s⁻¹. The results of parameters were presented in Table 2.

Table 1. Statistics describing the fitted curves of the drag dependent on velocity.

<table>
<thead>
<tr>
<th>Subject</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>TI</td>
<td>27.8 ± 2.6</td>
<td>29.0 ± 2.7</td>
<td>27.3 ± 2.1</td>
<td>28.0 ± 2.0</td>
</tr>
<tr>
<td>HY</td>
<td>23.8 ± 2.0</td>
<td>21.3 ± 2.1</td>
<td>21.9 ± 2.0</td>
<td>20.5 ± 2.0</td>
</tr>
<tr>
<td>HF</td>
<td>22.5 ± 2.0</td>
<td>24.2 ± 2.1</td>
<td>24.1 ± 2.0</td>
<td>20.8 ± 2.0</td>
</tr>
<tr>
<td>KS</td>
<td>19.6 ± 2.0</td>
<td>20.4 ± 2.0</td>
<td>20.6 ± 2.0</td>
<td>2.29 ± 2.0</td>
</tr>
<tr>
<td>AN</td>
<td>22.0 ± 2.1</td>
<td>22.9 ± 2.1</td>
<td>1.99 ± 2.0</td>
<td>2.00 ± 2.0</td>
</tr>
<tr>
<td>YH</td>
<td>23.5 ± 2.1</td>
<td>20.4 ± 2.1</td>
<td>21.6 ± 2.0</td>
<td>2.08 ± 2.0</td>
</tr>
<tr>
<td>HA</td>
<td>23.7 ± 2.5</td>
<td>24.8 ± 2.5</td>
<td>2.22 ± 2.0</td>
<td>2.03 ± 2.0</td>
</tr>
<tr>
<td>SY</td>
<td>26.7 ± 2.3</td>
<td>23.1 ± 2.3</td>
<td>2.01 ± 2.0</td>
<td>2.23 ± 2.0</td>
</tr>
<tr>
<td>SD</td>
<td>2.6 ± 2.3</td>
<td>2.8 ± 2.3</td>
<td>0.12 ± 2.0</td>
<td>0.14 ± 2.0</td>
</tr>
</tbody>
</table>

A = coefficient of proportionality; n = power of the velocity. A, B, C, D = sort of swimwear (see Figure 1).

As the results show, neither A nor n differed significantly among swimwear conditions. Although the estimated values of drag at swimming velocities of 1.2, 1.5, and 1.8 m•s⁻¹ were lower by 1-5 N (2-6%) in 3 new types of swimwear than those in conventional wear, the differences in drag were not statistically significant at all velocities among swimwear conditions, either. Therefore, no significant drag reduction effect of new types of swimwear could be detected. When compared, the estimated drag values at the same velocity among the new types of swimwear, the difference was quite small and less than 1.5%.

Table 2. Mean values of estimated drag at velocities of 1.2, 1.5, and 1.8 m•s⁻¹ swimming with each swimwear condition.

<table>
<thead>
<tr>
<th>Subject</th>
<th>1.2 m•s⁻¹</th>
<th>1.5 m•s⁻¹</th>
<th>1.8 m•s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>34.7 ± 2.6</td>
<td>35.2 ± 2.5</td>
<td>35.5 ± 2.5</td>
</tr>
<tr>
<td>B</td>
<td>35.2 ± 2.6</td>
<td>35.4 ± 2.7</td>
<td>35.4 ± 2.7</td>
</tr>
<tr>
<td>C</td>
<td>35.1 ± 2.7</td>
<td>34.9 ± 2.7</td>
<td>34.9 ± 2.7</td>
</tr>
<tr>
<td>D</td>
<td>35.2 ± 2.8</td>
<td>34.5 ± 2.7</td>
<td>34.4 ± 2.7</td>
</tr>
</tbody>
</table>

The rate of energy expenditure (E) during swimming is a function of the power to overcome drag (Pd), gross efficiency (eg), and propelling efficiency (ep) (Toussaint and Hollander 1994).

E = Pd / (ep • eg) (Eq.1)

In turn, Pd can be calculated from the product of drag (Fd) and velocity (v). Furthermore, Fd is given by;

Fd = A • v^n (Eq.2)

Therefore;

E = Fd • v / (ep • eg) = A • v^n / (ep • eg) = A • n+1 / (ep • eg) (Eq.3)

 Integration of this equation gives the energy expenditure (E) to swim a certain distance (d) at a given velocity or in a certain time (t);

E = A • v^n / (ep • eg) = n+1 / (ep • eg • t) (Eq.4)

Table 3. Estimated best times for the 100m, 200m, and 400m when swimming with each swimwear.

As the results show, neither A nor n differed significantly among swimwear conditions. Although the estimated values of drag at swimming velocities of 1.2, 1.5, and 1.8 m•s⁻¹ were lower by 1-5 N (2-6%) in 3 new types of swimwear than those in conventional wear, the differences in drag were not statistically significant at all velocities among swimwear conditions, either. Therefore, no significant drag reduction effect of new types of swimwear could be detected. When compared, the estimated drag values at the same velocity among the new types of swimwear, the difference was quite small and less than 1.5%.

Table 3. Estimated best times for the 100m, 200m, and 400m when swimming with each swimwear.

<table>
<thead>
<tr>
<th>Subject</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>100m</td>
<td>57.0 ± 2.6</td>
<td>56.9 ± 2.5</td>
<td>57.0 ± 2.5</td>
<td>57.2 ± 2.5</td>
</tr>
<tr>
<td>200m</td>
<td>2'04.5 ± 5.5</td>
<td>2'02.4 ± 4.7</td>
<td>2'02.8 ± 4.1</td>
<td>2'03.0 ± 4.7</td>
</tr>
<tr>
<td>400m</td>
<td>4'24.1 ± 11.5</td>
<td>4'19.9 ± 9.5</td>
<td>4'20.7 ± 8.5</td>
<td>4'21.3 ± 9.7</td>
</tr>
</tbody>
</table>

CONCLUSION
Even if no major differences in drag were found among swimwear, our results suggest that the observed 2-6% reduction, even if non significant, could indeed explain the observed competitive advantage.

REFERENCES


ACKNOWLEDGEMENTS
This study is partly supported by a Grant-in-Aid for THE DESCENTE AND ISHIMOTO MEMORIAL FOUNDATION FOR THE PROMOTION OF SPORTS SCIENCE.

Relationship between Heart Rate and Water Depth in the Standing Position

Onodera, S. 1, Yoshioka, A. 1, Matsumoto, N. 1, Takahara, T. 1, Nose, Y. 1, Hirao, M. 1, Seki, K. 2, Nishimura, K. 3, Baik, W. 1, Hara, H. 1, Murakawa, T. 3

1Kawasaki University of Medical Welfare, Kurashiki City, Japan
2University of Marketing and Distribution Sciences, Kobe City, Japan
3Hiroshima Institute of Technology, Hiroshima City, Japan
4Tokai University, Hinozuka City, Japan

The purpose of this study was to clarify the relationship between heart rate and water depth during standing submersion. Seven volunteers participated in this study. Subjects were in a standing position, in a test tank, for nine conditions of water depth. The water temperature was 34°C. Heart rate significantly decreased during increase of water depth, and significantly increased during decrease of water depth. The changes in heart rate were statistically different (ANOVA, P<0.05). It was considered that it was due to the action of the hydrostatic pressure and the autonomic nervous system upon heart rate. The findings of this study indicated changes of heart rate at rest during standing in water of thermal neutral temperature would differ between increasing and decreasing water depth.

Key words: Heart rate, Water depth, Standing, Hydrostatic pressure, Autonomic nervous system

INTRODUCTION
It is well known that, during water immersion, bradycardia and increases in stroke volume are induced by the effect of hydrostatic pressure. It was clarified before that heart rate (HR) was significantly decreased during standing in water (Onodera et al. 2001). Onodera et al. (1998) checked that this phenomenon was not only present in young but also in old persons, and that it was no relation of differences between the sexes. It was also observed that the changes in the cross sectional area of the inferior vena cava depended upon the water depth, while standing in water, indicating the acceleration of the venous return (Onodera et al. 2001, Onodera et al. 2006). These data suggest that a decrease of heart rate depends on the effect of hydrostatic pressure. Changes of cross sectional area of the inferior vena cava was connected with changes of HR (Delahouse et al. 2005). However, it was unclear whether the change of HR with change of water level was associated with the specific depth or not. The purpose of this study was to clarify the relationship between heart rate and water depth in different water levels.

METHODS
Seven volunteers participated in this study (age: 23 yrs, height: 173 cm, weight: 66 kg). All subjects signed an informed consent. Participants maintained a standing position of rest on land and in a test tank 180x180x200cm. Water depth was controlled using the two water pumps of an effluent standard of 50 l/min (PSK-65010, KOUSHINN Co., Ltd, Japan). Nine conditions of water depth (on land, knee joint, greater trochanter, xiphoid process, under the collarbone, xiphoid process, greater trochanter, knee joint, on land) were used, being each one kept for one min. Change of water depth took a same period of time, such as: from knee joint to greater trochanter, and from greater trochanter knee joint to knee joint. Heart rate was continuously measured using waterproof electrocardiograph (DS-2022, FUKUDA DENNSHI Co., Ltd, Japan). Water and room temperature was maintained at 34°C and 28°C, respectively. Data were expressed as mean and SD. ANOVA and paired t-test were used to determine the significance of statistical difference. The level of significance was set at p<0.05.
RESULTS
Fig. 1 shows the kinetics of the heart rate in each condition of water depth. Heart rate significantly decreased during increase of water depth (on land: 80 (SD: 9) b/m, knee joint: 73 (SD: 7) b/m, greater trochanter: 70 (SD: 7) b/m, xiphoid process: 63 (SD: 7) b/m, under the collarbone: 62 (SD: 9) b/m). In the other hand, heart rate significantly increased during decrease of water depth (xiphoid process: 62 (SD: 4) b/m, greater trochanter: 64 (SD: 9) b/m, knee joint: 68 (SD: 5) b/m, on land: 77 (SD: 8) b/m). The changes in heart rate were statistically different (ANOVA, P<0.05). The heart rate was significantly lower than those on land. The heart rate in greater trochanter was significantly lower than those of increase of water depth. These data suggest that the heart rate could not always agree with identical water depth.

DISCUSSION
In this study, there was a significant difference in HR in spite of the same water depth. It was considered that these phenomena were related to the two factors of hydrostatic pressure and the autonomic nervous system. Onodera et al. (2001) reported that stroke volume calculated from left ventricular end-diastolic dimension and lift ventricular end-systolic dimension significantly increased according with increasing water depth and HR significantly decreased according with increasing water depth. Schipke and Pelzer (2001) reported that immersion under pool conditions was a powerful stimulus for both the sympathetic and parasympathetic nervous system, and that as neither the heart rate nor the heart rate variability (HRV) changed on going from immersion to submersion, the parasympathetic activation was probably due to hemodynamic alterations. Delahoche et al. (2005) reported that the change in HR did not differ between breath-hold divers and non-divers, and that negative linear relations were found between ΔHR and ΔSaO2 in both divers and non-divers. Perini et al. (1998) reported that the total power of HRV was no different between the supine and sitting positions in air during rest, whereas they increased in water. Previous studies suggest that water immersion at rest causes an increase in the central venous pressure and total power of HRV (Delahoche et al. 2005, Lemaitre et al. 2008, Onodera et al. 1998, 2001 and 2006, Perini et al. 1998 and Schipke & Pelzer 2001). The finding of this study indicates that change of heart rate would differ between increasing and decreasing water depth, and be controlled by the autonomic nervous system.

CONCLUSION
Changes of heart rate at rest during standing in water of thermal neutral temperature would differ between increasing and decreasing water depth.

REFERENCES
Oxygen Uptake Kinetics Around the Respiratory Compensation Point in Swimming

Pessôa Filho, D.M.¹, Reis, J.F.², Alves, F.B.², Denadai, B.S.¹

¹Paulista State University, Brazil
²Faculty of Human Kinetics, Technical University of Lisbon, Portugal

The purpose of this study was to describe VO₂ kinetics throughout the heavy and severe domains during swimming. Nine swimmers completed two swimming tests to measure the conditioning indexes (ventilatory threshold (VT), respiratory compensation point (RCP), and VO₂max) and VO₂ kinetics (two trials intensities set at 2.5% below and above the crawl velocity at RCP, lasting 420s). In both cases, a portable breath-by-breath system was connected to a respiratory snorkel and valve was used. The trial below RCP elicited only a sub-maximal rate (91.6 ± 5.7% VO₂max), with a slow component of 391 ml·min⁻¹ beginning after 154s. The trial above RCP showed a time delay of 188s for the slow component (399 ml·min⁻¹), eliciting a rate of 104.6 ± 9.5% VO₂max. Thus, expected VO₂ kinetics for heavy and severe domains was characterized around RCP.

Key-word: VO₂ kinetics, heavy and severe domains, respiratory compensation point

INTRODUCTION

The boundary between heavy and severe exercise denotes a considerable change in exercise tolerance. According to Jones & Poole (2005), the upper boundary for the heavy domain is defined as the highest exercise intensity in which oxygen uptake (VO₂) and blood lactate concentration ([lactate]) can be maintained at an elevated but steady-state level. By definition, both critical power (CP: the asymptote of the power (P)–time (t) relationship, represents the limiting parameter to the aerobic supply, comprising the notion that if P ≤ CP, the anaerobic supply is never required, and endurance time is infinitely long (Morton, 2006) and maximal lactate steady-state (MLSS: highest constant workload that can be maintained over time without continuous blood lactate accumulation – Beneke, 2003) match the physiological responses encompassed in the upper boundary of the heavy domain.

However, CP intensity cannot be maintained without a substantial increase in blood lactate concentration, and other physiological parameters (Pringle & Jones, 2002, Dekkerle et al., 2003). Comparisons between the CP and power associated to MLSS suggest that both are different and should not be used interchangeably (Pringle & Jones, 2002). Moreover, the critical swimming velocity (CV), corresponding to the slope of the distance–time relationship (Sd–t), lies within the severe intensity domain with the physiological responses characterizing the heavy and severe intensity domains when swimming 5% slower and 5% faster than Sd–t, respectively (Dekerle et al., 2009). The dependence of the P-t relationship on the choice of predictive trials may explain the misinterpretation of its mathematical definition as the highest work rate that can be maintained for a very long time without fatigue (Dekerle et al., 2009).

Exercising at 50% of the difference between the mode–specific LT and VO2max (50%ΔVO2) is an alternative index to the transition between heavy and severe domains (Jones & Poole, 2005). Surprisingly, whereas the LT has been estimated from gas-exchange responses as ventilatory threshold (VT: rising in the VE/VO2 curve with no change in the VE/VCO2 curve – Beaver et al., 1986), the respiratory compensation point (RCP: point in the plot of VE vs. VCO2 where VE rises more rapidly in a phase of relative hyperventilation – Beaver et al., 1986) for metabolic acidosis and buffering events in the tissues, has not clearly demarcated the upper boundary of the heavy domain. Although no significant differences were obtained between VO2 and power output at CP and RCP in cycling (Dekerle et al., 2003). Thus, the purpose of this study was to describe VO2 kinetics throughout the heavy and severe exercise domains during front-crawl swimming, considering RCP as the transition parameter between them.

METHOD

Subjects: Nine well-trained male swimmers (21.0 ± 7.2 yr, 68.6 ± 9.2 kg, 178.2 ± 6.4 cm, 13.2 ± 4.1% body fat, and -4.0 ± 0.7 L·min⁻¹ VO2max) participated of this study. All subjects were advised to tests protocols and gave written consent. This research was approved by the local Ethics Committee.

Experimental design: The subjects were required to perform three stages of experimentation. The first stage involved the determination of VT, RCP and VO2max. The second stage involved two swimming sessions with the subjects performing two repetitions of square-wave transitions, from rest to one of two exercise intensities set at 2.5% below (v₋2.5% and above (v₊2.5%) the velocity at RCP, corresponding to 36.3 ± 7.0% and 74.1 ± 11.4% of the delta between velocity at VT and VO2max. No more than two transitions were completed in one day, with at least 1h of recovery between transitions. All the procedures were not extended beyond 3–4 weeks for each subject, and the study was completed in about eight weeks. All tests were performed in a 50-m indoor swimming pool. During the exercise tests, pulmonary gas exchange was determined breath-by-breath with a portable automated system (K4b2, Cosmed), which was calibrated before each test, and connected to the swimmer by a special respiratory snorkel and valve system, previously validated by Keskinen et al. (2002).

Incremental protocol: Subjects performed an intermittent incremental test (300-m stages) to exhaustion. The velocity increments were delineated to four or five percentages designed to attain the 400-m maximal swimming velocity at the last stage. The breath-by-breath VO₂ responses were smoothed and averaged every 30s. VO2max was calculated as the highest 30s value achieved during the incremental test. The swimming velocity related to the VO2max (vVO2max) was defined as the lowest velocity that elicited VO2max (Demarie et al. 2001). The lower and upper boundary for heavy intensity domains were determined from gas exchange responses at VT and RCP respectively, following the recommendations of Beaver et al. (1986). VT was examined visually using plots of V̇E/V̇CO₂, V̇E/VO₂, end-tidal PCO₂ (PETCO₂) and end-tidal PO₂ (PETO₂). The criteria used for determination of VT and RCP were a non-linear increase in VE/VO₂ and PETO₂ curves without a corresponding change in VE/VCO₂ and PETCO₂ curves; and an increase in both VE/VO₂ and VE/VCO₂ and a decrease in PETO₂, respectively. VT and RCP location point were estimated by two independent observers. The highest 30-s average VO₂ for these steps was considered the VO2 at VT and RCP.

VO₂ kinetic modeling: Subjects performed two repetitions of square-wave transitions of 7 min duration at the two exercise intensities on separate days. After a 3-4 min warm-up at a low swimming velocity followed by 5 min of rest, the subjects were instructed to perform the required intensity. Intensities were set at 2.5% below and above the velocity at RCP, which corresponded to 1.35 ± 0.05 m·s² and 1.28 ± 0.05 m·s⁻², respectively. For each exercise transition, the breath-by-breath data were interpolated to give second-by-second values. For every each intensity, the transitions were then synchronized with the start of exercise. The baseline VO2 was defined as the average VO2 measured during resting 30s before the start of each transition.

\[ VO₂(t) = VO₂_{2a} + A_1 \left(1 - e^{(-t/Td_1/\tau_1)}\right) + A_2 \left(1 - e^{(-t/Td_2/\tau_2)}\right) \] (1)
The physiologically relevant increase in VO2 is the amplitude of phase I (A1'), or primary component, which was calculated from:

$$A'_1 = A_1 \left(1 - e^{-\left(\frac{(TD1-TD2)}{\tau_1}\right)}\right)$$

(2)

Because the asymptotic value (A2) may represent a higher value than that actually reached at the end of the exercise, the value of the VO2 slow exponential term at the end of exercise was defined as (A2'):

$$A'_2 = A_2 \left(1 - e^{-\left(\frac{(ED-TD2)}{\tau_2}\right)}\right)$$

(3)

where ED is the exercise duration.

Statistical analysis: The values were expressed as mean ± SD. The normality of data was checked by Shapiro-Wilk test. The statistical difference between two means was checked by a paired Student’s t-test (2-tailed). Bi-exponential analyses were performed by the least squared residuals method. The level of significance was set at p < 0.05. All statistical analyses were performed by utilizing software SPSS 17.0.

RESULTS

Variables presented in Table 1 describe the physiological and performance parameters related to the indices delimiting exercise domains. The RCP was observed to correspond with the midpoint between VT and VO2max, but substantial variability was observed, as shown on Table 1.

Table 1: Parameters for incremental test. n = 9.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VO2relative to BW (ml·min⁻¹·kg⁻¹)</th>
<th>Relative to VO2max (%)</th>
<th>Velocity (m·s⁻¹)</th>
<th>Delta (%Δ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2max</td>
<td>58.0 ± 5.1</td>
<td>100</td>
<td>1.40 ± 0.03</td>
<td>100</td>
</tr>
<tr>
<td>VT</td>
<td>41.1 ± 5.7</td>
<td>70.5 ± 5.0</td>
<td>1.21 ± 0.06</td>
<td>0</td>
</tr>
<tr>
<td>RCP</td>
<td>49.9 ± 4.9</td>
<td>86.0 ± 4.9</td>
<td>1.32 ± 0.05</td>
<td>51.0 ± 141.5</td>
</tr>
</tbody>
</table>

The trivial difference between predetermined and performed trials above (1.35 ± 0.05 m·s⁻¹ and 1.34 ± 0.05 m·s⁻¹, p = 0.54) and below (1.28 ± 0.05 m·s⁻¹ and 1.28 ± 0.05 m·s⁻¹, p = 0.78) RCP ensured the effective control of the velocity under the test condition. The velocity measured during trials was closer to the defined velocity in both trials above (2.0 ± 1.2%) and below (~2.7 ± 0.8%) the RCP.

Table 2: Parameters of VO2 on-kinetics around RCP. n = 9.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2.5% below RCP</th>
<th>2.5% above RCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2baselin (ml·min⁻¹)</td>
<td>474.90 ± 91.24</td>
<td>523.78 ± 79.08</td>
</tr>
<tr>
<td>TD1 (s)</td>
<td>17.6 ± 3.3</td>
<td>14.0 ± 5.6†</td>
</tr>
<tr>
<td>t1 (s)</td>
<td>17.8 ± 7.1</td>
<td>16.1 ± 4.9</td>
</tr>
<tr>
<td>A1' (ml·min⁻¹)</td>
<td>2.784.93 ± 616.02</td>
<td>3.247.04 ± 669.99†</td>
</tr>
<tr>
<td>R²</td>
<td>0.97 ± 0.02</td>
<td>0.93 ± 0.04</td>
</tr>
<tr>
<td>TD2 (s)</td>
<td>153.8 ± 42.5</td>
<td>188.4 ± 97.2</td>
</tr>
<tr>
<td>t2 (s)</td>
<td>99.5 ± 82.2</td>
<td>73.8 ± 67.4</td>
</tr>
<tr>
<td>A2' (ml·min⁻¹)</td>
<td>391.24 ± 236.61</td>
<td>399.40 ± 270.49</td>
</tr>
<tr>
<td>R²</td>
<td>0.69 ± 0.26</td>
<td>0.66 ± 0.23</td>
</tr>
<tr>
<td>EVO2 (ml·min⁻¹)</td>
<td>3.176.17 ± 647.01</td>
<td>3.646.45 ± 823.11†</td>
</tr>
<tr>
<td>A',%EVO2</td>
<td>12.4 ± 7.3</td>
<td>10.5 ± 5.3</td>
</tr>
<tr>
<td>TotalVO2 (ml·min⁻¹)</td>
<td>3.651.07 ± 660.36</td>
<td>4.170.23 ± 810.11†</td>
</tr>
<tr>
<td>%VO2max attained</td>
<td>92.0 ± 6.0</td>
<td>105.0 ± 9.5†</td>
</tr>
</tbody>
</table>

EEVO2 is the increase in VO2 above baseline at end of exercise. Marked differences (p < 0.05) were observed in relation to 2.5% below RCP. Time parameters of VO2 on-kinetics seems not to differ substantially between trials around RCP, with the exception of TD1 (p = 0.03) (Table 2). This scenario suggests that the response for the primary component begins early while swimming above rather than below RCP. The amplitude parameters account for the noticeable differences between trials in each condition. Primary amplitude, end-exercise VO2 (EEVO2), and entire VO2 (TotalVO2) showed difference for their paired values in each trial (p values of 0.001, 0.001, and 0.000, respectively) (Table 2). There was no tendency for the onset of the slow component (TDs) to occur earlier as exercising above (188.4%) and below (153.8%) RCP intensity, neither to differ in amplitude (399.4 and 391.2 ml·min⁻¹ above and below RCP, respectively), or in relative contribution to the EEVO2 (10.5% and 12.4% above and below RCP, respectively) (Table 2). None of the subjects reached the exhaustion in either trial (above and below RCP), however because of the slow component, TotalVO2 eliciting 104.57 and 91.58% of VO2max while swimming above and below RCP, respectively. The on-transient for VO2 above and below RCP is illustrated for one swimmer in the Figure 1.

DISCUSSION

In swimming, heavy and severe domains of exercise intensity have not been studied by means of pulmonary VO2 on-kinetics. In a recent study, Dekerle et al. (2009) concluded that CV lies on the boundary between the heavy and severe intensity domains within a range of ± 5%, since post exercise VO2 (reaching only 87 ± 14%VO2max) and [lactate] remained stable when swimming 5% below CV. In contrast, when swimming 5% above, both a rapid increase in [lactate] and quick attainment of peak VO2 were observed. Data from the present study corroborates with these results in an even narrower range (less than 5% was the difference between slower and faster trials) around the RCP, by on-transient VO2 kinetics. The trial ~2.7% below RCP was performed at v36.8 ± 8.5% VO2max (~12.8 ± 0.05 m·s⁻¹ or 91 ± 2% of vVO2 2max), eliciting a sub-maximal VO2 (about 92.0 ± 6.0%VO2max), after a delayed steady-state (154%) of an amplitude of 391 ml·min⁻¹. The VO2 in the trial above ~2% of RCP (~71.1% ± 17.1%VO2max, about 1.3 ± 0.05 m·s⁻¹ or 96.1 ± 2.4% of vVO2 2max) presented a delayed (188%) amplitude of 399 ml·min⁻¹ limited trunked at its maximum rate (105.0 ± 9.5%VO2max). Similar results were previously observed by Demarie et al. (2001) with pentathletes, whose VO2 slow component rose to 114 ± 10%VO2 2peak when swimming at a velocity corresponding to 96% of VO2peak. Swimming at previously determined VO2max, high level male swimmers exhibited a VO2 slow component of 274.1 ± 152.8 ml·min⁻¹ (Fernandes et al., 2003). These authors have analyzed the VO2 changes (ΔVO2) between the second minute to the end of exercise for determination of the amplitude of VO2 slow component, arguing that (1) onset of slow component has an earlier time delay in the severe than in the heavy domain; (2) there is no consensus about the algorithm to fit VO2 slow component kinetic; and (3) there is a high variability in the ampli-
Hormonal, Immune, Autonomic and Mood State Variation in the Initial Preparation Phase of a Winter Season, in Portuguese Male Swimmers

Rama, L. 1, Alves, F. 2, Teixeira, A. 1

1 Research Centre for Sport and Physical Activity, University of Coimbra, Portugal
2 Faculty of Human Kinetics, Technical University of Lisbon, Portugal

At the initial phase of seasonal preparation, swimmers are submitted to a sudden increment of training load. Because the amount of training is normally less than the maximal that will be imposed later on in the season, coaches do not pay much attention to how athletes accommodate this increment. This study aims to analyse at rest, the variation of serum and salivary cortisol and testosterone, salivary IgA, HRV and the Profile of Mood States (POMS) after the first meso-cycle of a winter swimming season in a sample of 13 male Portuguese swimmers of national level. In this study, the impact of the initial phase of seasonal training on the athlete’s adaptation in a multidimensional approach was investigated. Significant variation in hormonal, mood and autonomic variables were found, which justifies paying attention to athletes work tolerance, especially in the initial phase.

Key words: salivary IgA, heart rate variability, hormonal response, POMS

INTRODUCTION

Swimming as an endurance sport is recognized as a sport where athletes are normally submitted to heavy training loads. In seasonal planning the option at the beginning of the season of a marked load in the training volume is common, aiming to hit as soon as possible, high volumes focusing on aerobic adaptation (Pyne & Goldsmith, 2005). Because this does not correspond yet to the maximal requirements of the training season, coaches do not always pay enough attention to the inability of athletes to adapt to this sudden increment of training volume (Maggioso, 2003). Although their performance capacity does not seem to be impaired, the high requirement of body resources often stresses the athlete’s adaptation capacity. This precarious balance between positive and negative influence of the training stimulus and the related fatigue, modulate training adaptation. In the domain of control of training, researchers have put their efforts into looking for biological and psychological markers that can be used in an effective way to prevent inadequate adaptation (Norris & Smith, 2002).

The hormonal response to training is a recurrent strategy in the control of training. Among the several markers used, the hormones testosterone and cortisol were among the most used to follow the response to training load (Hooper, Mackinon et al, 1999). In brief, cortisol is considered because of its response to stress and catabolic action, while testosterone is used because is considered to be a marker of anabolic function. Looking at the resting values of these hormones, the literature suggests that a decrease of testosterone and increase of cortisol in endurance training athletes is common (Duclos et al. 2001). Although the controversy persists, generally the reduction of cortisol is necessary as a pre-requisite for performance improvement (Bonifazi et al. 2000). The salivary content that corresponds to the free and biological active form of the hormones may constitute a less invasive and preferable marker (Paccotti et al. 2005). It is accepted that salivary IgA is a mucosal immune marker that shows reduced values after long periods of training which could compromise training and performance capacity (Pyne et al. 2000; Gleeson et al. 2000).

Heart rate variability (HRV) has become a promising and useful indicator that reflects the autonomic response to training. Autonomic

REFERENCES


imbalance associating increased sympathetic activity and reduced vagal tone has been proposed as a marker of the negative impact of poorly tolerated training load (Atlaoui et al. 2007). The interest in HRV is also reinforced because of the non-invasive approach as it is possible to assess it through the use of portable heart rate monitors able to record the R-R interval.

Mood states reflect the impact of training as perceived by the swimmers, and is known to be affected by difficulties of accommodation to the requirements of the training and often constitute the first signal of problems with load adaptation. The POMS questionnaire is one of the most applied instruments in sports to access alterations of athlete mood states induced by training (Morgan et al. 1988).

In this study, the aim is to control the response of these variables in resting condition just before the beginning of training season and after the first meso-cycle characterized by the sustained increased volume. The main interest is to focus on the chronic effect of training.

**METHODS**

The sample in this study consisted of 13 male swimmers of national Portuguese level (17.2 ± 1.3 years old, 174.9 ± 5.8 cm, 65.8 ± 6.8 kg of height and weight, respectively). All subjects were informed and signed the informed consent. Training volume, intensity and time spent in dry land activities were controlled. Intensity is expressed in arbitrary units of load (Mujika et al. 1995). Blood and saliva samples were collected: 1) in the beginning of the winter season, after an off training period of 6 weeks (t0); 2) after 7 weeks of training (t1), by veno puncture, always at the same time of the day (between 15 and 17h. At (t1), a time lapse of 48 hours of rest after the last training session was respected.

Serum cortisol and free testosterone were determined by Electrochemiluminescent immuno-assay with the Immulite® 2000 analyser. The salivary content of cortisol and testosterone were determined by ELISA (Salimetrics® USA). Salivary IgA was determined by ELISA as it was described elsewhere (Li & Gleeson, 2004). Salivary IgA secretion rate was calculated from salivary flow rate and the IgA concentration.

For the HRV assessment, the swimmers lay 8 minutes in the supine position, wearing a heart rate monitor (Polar® S810) selected for RR interval recording. 5 minutes were used for HRV analysis, excluding the first 2min and the last minute. During heart rate recording, the athletes were required to synchronize their breath pattern at 12 cycles per min-1 with the help of a sound pacer, in order to avoid perturbation determined by breathing. The software Polar Performance SW® was used to transfer data from the monitors and to analyze and correct for ectopic and missing beats. The HRV analysis was done with the Kubios HRV Analysis Software (Kuopio, FIN). Time SDNN was used as a marker of global heart rate variability. The frequency analysis was done through fast Fourier transformation controlling the LF power, HF power and LF/HF ratio upon the R-R interval power spectra. The recommendations of the Task Force of the European Society of Radiology and North American Society Electrophysiology were respected. For the mood state assessment, the Portuguese version of the Profile of Mood States POMS short form was used. Statistical analysis using non parametric Wilcoxon test was conducted (p<0.05) for detection of differences among evaluation moments.

**RESULTS**

During the study period, the volume of training increased gradually from 20 km to 42 km/week with a mean rate of increase of 17.5% per week. The general workload represented a mean of 16 to 20 hours of pool training and 3 to 5 hours of dry land training.

Looking for hormonal changes after the first 7 weeks of the winter swimming season, a significantly higher value of serum cortisol, (p=0.046) and salivary cortisol (p=0.013) were found. Although the free testosterone remained stable during this period, the testosterone to cortisol ratio decreased significantly (p=0.028). The free testosterone did not show any variation in serum or saliva. The salivary and serum or plasmatic content of both hormones were significantly correlated (r=0.603; p=0.008) for cortisol and (r=0.709; p=0.001) for testosterone. Although an apparent elevation, the salivary IgA concentration and secretion rate did not reveal significant alterations.

Regarding the HRV analysis, no significant alteration was found in the time parameter SDNN after the training period. The analysis of frequency revealed no variation in absolute power. However, it was possible to appreciate an elevation of LF / HF due to the large increment of LF and the decrease of HF (p=0.016). Other observed alterations were in relative power the decrease of HF (%) and almost significant elevation of LF (%). The total score of POMS also showed an alteration towards significantly worse scores (p=0.03).

**DISCUSSION**

During the study period an important increment of training load, especially in training volume occurred. The elevation of cortisol normally represents a physiological response to the energetic and metabolic needs of exercise. Our results confirm the suggestion that endurance training may cause an increase in resting cortisol concentrations and an apparent stabilization of the testosterone response. These results could illustrate an adaptive mechanism from which swimmers could be prevented from an important anabolic action leading to increased body mass, thus impairing the aerobic capacity. Our results highlight the interest of the use of cortisol as a marker of the impact of chronic training, as it showed higher sensibility than testosterone. The significant correlation between blood and saliva cortisol allows the use of the latter, avoiding the more invasive procedure. The mucosal immune function seems not to be affected as the IgA parameter did not show significant variation.

Autonomic imbalance associating increased sympathetic activity and reduced vagal tone has been proposed as a marker of excessive fatigue and impaired performance. Among the parameters in the frequency domain of HRV, the higher LF / HF ratio seems to confirm the sensitivity to detect the increment of the magnitude of training and the trend to identify in this condition the elevation of sympathetic influence in the autonomic regulation. This initial training phase seems to affect seriously the mood states. Indeed, this result support the importance of psychological monitoring to prevent problems in the training adaptation process.

**CONCLUSION**

Although the most important training loads of the season do not occur at the initial phase of swimming preparation, it can be concluded...
that the sudden increase of the volume of training causes significant alterations in several markers, namely the increase in the concentration of the stress hormone cortisol, the autonomic imbalance through the reinforcement of sympathetic regulation. As previously found (Rietjens et al. 2005), the mood proves to be a sensitive marker of the impact of training and its deterioration seems to indicate problems in the adaptation to the training process.

These changes could correspond to the normal overload, but they should be considered carefully by coaches in order to optimize performance development. More precisely, monitoring psychological adaptation to training seems to be a good approach to prevent failure in the tolerance of individuals to workload. Our results seem to agree with those of Norris & Smith, (2002) who advocate an adequate planning of recovery strategies, that could contribute to avoiding the negative impact of the sudden increase of training load especially at the initial preparation phase.

REFERENCES


ACKNOWLEDGEMENTS

This project was financed by the Portuguese foundation for Science and Technology (FCT PTDC/ DES/ 68647/ 2006).
Oxygen Uptake Kinetics and Performance in Swimming

Reis, J.F., Alves, F.B.

CIPER, Faculty of Human Kinetics, Lisbon, Portugal

The purpose of this study was to compare the VO2 kinetics in two sub-maximal intensities in elite (E) and club-level (C) swimmers. After previous determination of VO2 max and ventilatory threshold (VT), fourteen swimmers were divided into two groups: E (n = 7; 22.7 ± 2.7 yr) and C (n=7; 18.8 ± 1.4 yr) and performed two constant velocity swimming bouts at 25% (Heavy) = VT + 0.25 x (VO2 max - VT)) and 70% (Severe) for determination of VO2 kinetics. The E group presented a faster time constant of the primary phase VO2 response than C in severe swimming (13.3±3.4s and 18.4±4.6s, respectively; p<0.05) which was also correlated with endurance performance, recorded as the time attained in an official 400 freestyle event (r= 0.6, p<0.05).

Keywords: oxygen uptake kinetics, swimming performance, time constant

INTRODUCTION

Several studies have contemplated the oxygen uptake response (VO2) in constant load terrestrial exercises, such as cycling or running. At intensities below the ventilatory threshold (VT), after a delay-like cardio-dynamic phase (Tpi; time for completion of 63% of the response) is considered to be equivalent (within 10%) to the muscle VO2 kinetics, which can be reproduced other terrestrial activities. VO2 kinetics during swimming (13.3±3.4s and 18.4±4.6s, respectively, p>0.05) which can not be assumed that the VO2 kinetics during swimming transition per condition, which makes it difficult to determine parameter values.

The pulmonary time constant of the VO2 response of the primary phase (Tpi; time for completion of 63% of the response) is considered to be equivalent (within 10%) to the muscle VO2 kinetics, which can provide insightful information concerning the physiology of the working muscle (Jones & Koppo, 2005). Faster kinetics have been associated with performance and training status in studies conducted in cycling, rowing or running (Bailey et al., 2009; Ingham et al., 2007).

In swimming, the literature describing the VO2 kinetics response in constant load exercise is scarce and the studies performed only one exercise transition per condition, which makes it difficult to determine parameter estimates with an adequate degree of confidence (Demir et al., 2001, Fernandes et al., 2008, Rodriguez et al., 1999). To our knowledge the study of VO2 kinetics at two sub-maximal swimming intensities and their relation to performance has yet to be fully clarified. Since VO2 kinetics during high-intensity exercise is also influenced by exercise mode (Carter et al., 2000) and body position (Koga et al. 1999) it can not be assumed that the VO2 kinetics of swimming reproduce other terrestrial activities.

Therefore, the purpose of this study was to compare the VO2 kinetics at two sub-maximal intensities in elite (E) and club-level (C) swimmers. It was hypothesised that E have faster kinetics than C at both intensities.

METHODS

Fourteen highly trained male swimmers were divided into two groups (E (n = 7; 22.7 ± 2.7 yr.; 81.68 ±12.5 kg; 1.83 ± 0.10m) and C (n=7; 18.8 ± 1.4 yr.; 69.1 ± 8.4 kg; 1.77 ± 0.04 m) gave written informed consent to participate in the study, which was granted ethical approval by the Scientific Committee of the Faculty of Human Kinetics of the Technical University of Lisbon. The Elite group consisted of swimmers who represented the Portuguese National Team in International Competition in freestyle events (200 meter or above). Club level swimmers were characterized as having never represented their country at the senior level, but all of the subjects underwent regular training and competed regularly in National Championships.

The subjects were familiarised with the test procedures and equipment used in the experiment and were instructed to avoid strenuous exercise in the 24 hours preceding the test.

Swimmers were required to report to the pool on 3 occasions over a 10 day period. All the tests were interspersed with at least 24-h recovery. Subjects underwent a preliminary test comprising 5 x 200 m with 30 s rest and 5-10% velocity increments for determination of maximal oxygen uptake (VO2 max) and ventilatory threshold (VT). The last repetition was performed at maximal velocity (v_VO2 max) was recorded as the highest 30 s average and VT was established using the V-slope method (Beaver et al., 1986). On subsequent test days, the swimmers performed two 7-min square-wave transitions from rest to 25%Δ [VT + 0.25 x (VO2 max - VT)] (H) and 70%Δ (S) with 1-h rest in between. The subjects returned to the pool within one week to repeat the procedure, giving a total of two H and two S exercise transitions.

Heart Rate was recorded throughout each swimming bout and averaged every 30 s. Blood lactate concentration was determined after each square-wave transition (Lactate Pro (Arkray, Kyoto, Japan). All the tests were performed in front crawl with breath by breath analysis (K4b2, Cosmed, Italy) using a swimming snorkel (Aquatrainer, Cosmed, Italy), previously validated for determination of oxygen uptake kinetics (Reis et al., 2010). In-water starts and open turns without underwater gliding were implemented in each test.

The breath-by-breath data of the two repetitions at each swimming intensity were 1-s interpolated, time-aligned and averaged together in order to obtain a single set of data representative of H and S.

VO2 kinetics was modelled according to the following equation:

\[ VO_2(t) = \begin{cases} \frac{VO_{2base}}{t_d} e^{-\frac{t}{t_d}} & \text{for } t < t_d \\ VO_{2base} + A_p \left[ 1 - e^{-\frac{t}{t_d}} \right] & \text{for } t_d \leq t < t_d \tau \\ VO_{2base} + A_r \left[ 1 - e^{-\frac{t}{t_d}} \right] & \text{for } t_d \tau \leq t < t_d \end{cases} \]

where \( VO_2(t) \) represents the relative VO2 at a given time, \( VO_{2base} \) represents the rest VO2, \( t_d \) the time delay, the time constant and the amplitude of the primary phase and \( \tau \) the time constant of the slow component respectively. These parameters were calculated, by an interactive procedure, minimising the sum of the mean squares of the differences between the modelled and the measured VO2 values.

Because the asymptotic value of the second function is not necessarily reached at the end of the exercise, the amplitude of the VO2 slow component was defined as

\[ A_s = \frac{A_r}{\left( 1 - e^{-\frac{t_d}{\tau}} \right)} \]

where \( t_d \) was the time at the end of the exercise bout (Borrani et al. 2001). The modelling incorporated an individual "snorkel delay" (ISD) defined as \( t_{ISD} - t_f \) where \( t_{ISD} \) is the small time such that \( \Sigma R = t_f \) (Reis et al., 2010).

Endurance performance was recorded as the time performed in an official 400 meters freestyle competition within 1 month from the other tests (T400).

RESULTS

The swimmers responses obtained in the incremental test and in the square-wave transitions are given in Table 1 and 2, respectively.

Table 1 Mean ± SD of the metabolic and performance variables obtained in the incremental test, for Elite Swimmers, Club-level Swimmers and Combined group

<table>
<thead>
<tr>
<th>Variable</th>
<th>Elite</th>
<th>Club-level</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2 max (ml·kg-1·min-1)</td>
<td>25.7±3.5</td>
<td>21.3±2.9</td>
<td>24.5±4.0</td>
</tr>
<tr>
<td>VO2 max (mv·1)</td>
<td>1.52±0.05</td>
<td>1.40±0.12</td>
<td>1.43±0.08</td>
</tr>
<tr>
<td>VT (ml·kg-1·min-1)</td>
<td>42.7±2.0</td>
<td>41.0±8.0</td>
<td>41.9±5.7</td>
</tr>
<tr>
<td>Lamax (mmol·l-1)</td>
<td>9.6±1.8</td>
<td>11.2±1.4</td>
<td>10.4±1.8</td>
</tr>
<tr>
<td>HMax (b·min-1)</td>
<td>178±3.5</td>
<td>182±5.8</td>
<td>180±7.1</td>
</tr>
</tbody>
</table>
The E swimmers presented higher values for \( V_{O2\ max} \) than C, lower \( \pi_0 \) for S intensity swimming and T400 (240.1±2.5s and 262.7±5.9s, respectively, p<0.01). Neither of the other \( V_{O2} \) kinetics parameters differed between groups, nor did the heart rate response or the lactate concentration after each square-wave transition. When the entire group is considered, there was a positive correlation between T400 (251.4 ± 4.5s) and \( \pi_0 \) in both H (15.7±4.8s, r=0.6; p<0.05) and S (15.8±4.7, r=0.06; p<0.05) domains. No correlations were observed between the slow component amplitude and endurance performance in either swimming intensities, both considering the entire sample or the groups separately. The amplitude of the primary phase and the oxygen uptake at the end of each exercise bout were higher in S than in H exercise, whereas the slow component demonstrated the opposite trend. Figure 1 shows the \( V_{O2} \) data and the modelled response from one representative subject of each group during a transition to heavy swimming.

### Table 2 Mean ± SD parameters of the \( V_{O2} \) kinetics for transition from rest to \( \Delta25\% \) (heavy) and \( \Delta70\% \) (Severe) for Elite Swimmers (E), Club-level Swimmers (C) and Combined group (Comb).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Heavy Intensity</th>
<th>Severe Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E (C) Comb</td>
<td>E (C) Comb</td>
</tr>
<tr>
<td>( V_{O2\ base} )</td>
<td>9.6±2.2 10.5±2.1</td>
<td>10.6±2.0 11.0±1.8</td>
</tr>
<tr>
<td>( A_p )</td>
<td>38.1±3.4 34.0±3.3</td>
<td>39.9±4.5 40.6±4.8</td>
</tr>
<tr>
<td>( \tau_d )</td>
<td>11.0±2.9 12.5±2.9</td>
<td>11.5±3.2 12.2±2.7</td>
</tr>
<tr>
<td>( \pi_p )</td>
<td>3.7±2.1 5.8±2.8</td>
<td>5.0±2.5 2.9±1.1 3.2±1.5 3.1±1.3</td>
</tr>
<tr>
<td>( %A_w )</td>
<td>7.5±2.1 11.8±5.8</td>
<td>10.1±5.1 5.2±2.1 6.0±2.8 5.7±4.5</td>
</tr>
<tr>
<td>( T_d )</td>
<td>169.6±78 170.0±13</td>
<td>175.9±51 185.2±52 183.7±76 167.7±67.4</td>
</tr>
<tr>
<td>( EE V_{O2} )</td>
<td>49.7±2.8 50.1±6.1</td>
<td>48.2±4.9 55.0±2.4 53.7±5.7 53.5±4.4</td>
</tr>
<tr>
<td>( EE HR )</td>
<td>158.6±7.0 165.7±13</td>
<td>161.3±17 178.6±6 176±10.0 180±6.5</td>
</tr>
<tr>
<td>( EE La )</td>
<td>4.4±1.9 5.2±1.4</td>
<td>4.8±1.6 7.6±2.7 9.5±1.8 8.6±2.4</td>
</tr>
</tbody>
</table>

Amplitude \( (A_p, A_w) \), time delay \( (\tau_d, \tau_s) \), time constant \( (\tau_p, \tau_s) \), of the primary phase and slow component, respectively. \( %A_{sc} \): relative contribution of slow component in relation to the end-exercise \( V_{O2} \); \( V_{O2\ max} \) at the end of the end of the constant load exercise; \( EE HR \): heart rate at the end of the constant load exercise; \( EE La \): [La] at the end of exercise. \(^a\)Value for C swimmer is different from E, p<0.05. \(^b\)Value for S intensity is significantly different from H, p<0.05.

**DISCUSSION**

To our knowledge this is the first work to both incorporate multiple exercise transitions and exponential modelling of the \( V_{O2} \) response in swimming. Breath-by-breath data were collected from multiple transitions so that inherent breath-to-breath variability could be reduced and the primary phase of the \( V_{O2} \) response could be characterised.

The values determined for \( \pi_p \) were similar to those presented for trained runners and rowers (Borrani et al. 2001, Ingham et al. 2007). Although most studies in healthy young subjects have obtained \( \pi_p \) values that are usually between 20-35 s (32), athletes generally present faster kinetics. While it could be expected that the supine position and the predominance of upper arm use in swimming exercise would induce slower kinetics than upright leg exercise, that seems not to be the case in well trained swimmers. The specificity of swimming training was recently associated with enhanced \( V_{O2} \) kinetics obtained in arm cranking (Winlove et al. 2010), which is in accordance with the somewhat faster kinetics detected in the present study.

As expected, the amplitude of the \( V_{O2} \) primary component, end-exercise \( V_{O2} \) heart rate and the lactate values were significantly higher in severe compared to heavy exercise in both groups, like other exercise modes. These data suggest the recruitment of more muscle fibres and greater energy expenditure at higher intensities (Carter et al. 2002). The slow component was lower in severe intensity, which could be explained by the limitation of increase in the \( V_{O2} \) response by the attainment of the \( V_{O2\ max} \).

The Elite Group was characterized by a lower T400 and a higher \( V_{O2\ max} \) confirming the higher endurance and performance levels. Furthermore, \( \pi_p \) also differentiates between E and C swimmers, which seems to indicate that faster kinetics are associated with higher aerobic fitness and performance levels in swimming events, considering drag and stroke technique are similar between groups. Moreover, the difference was only significant in S swimming, which could be explained by the closeness of this intensity to the competition velocities. The decrease of \( \pi_p \) reflects an enlarged oxidative contribution to energy transfer which induces a lower initial oxygen deficit and smaller perturbation of the cellular redox potential and \( PCr \) decrease (Jones Koppo, 2005). The association between T400 and \( \pi_p \) in both intensities reinforces \( V_{O2} \) kinetics as a determinant in swimming events which endure both significant aerobic and anaerobic pathways, since it has been related to both increased time to exhaustion and fatigue tolerance (Bailey et al., 2009).

Our results agree with the latest literature which emphasizes \( V_{O2} \) kinetics as an important and useful parameter for coaches to access in elite athletes (Davison et al., 2009).

When measured at the same relative intensity, the slow component amplitude appears to be similar between elite and sub-elite swimmers and was not correlated with T400. Although it has been associated with metabolic inefficiency, it was similar in elite and club-level rowers (Ingham et al., 2007) which is in accordance with the present results.

**CONCLUSIONS**

The shorter time constant for the primary phase of the \( V_{O2} \) response in square-wave transitions from rest to heavy and severe swimming exercise seems to be related to higher aerobic fitness and performance levels in aerobic swimming events, whereas measured at the same relative intensity, the slow component amplitude appears to be similar between elite and sub-elite swimmers.

**REFERENCES**


Borrani, F., Candau, R., Millet, G.Y., Perrey, S., Fachslocher, J., Rouillon J.D. (2001). Is the \( V_{O2} \) slow component dependent on progressive

ACKNOWLEDGEMENTS
The first author gratefully acknowledges the ‘Fundação para a Ciência e Tecnologia, Portugal’ (‘The Foundation for Science and Technology’) for their doctoral fellowship award (reference number SFRH/BD/23351/2005).

Maximum Blood Lactate Concentration after two Different Specific Tests in Freestyle Swimming

Rozi, G. 1, Thanopoulos, V. 1, Dopsaj, M. 2
1Faculty of Physical Education and Sports Science, University of Athens, Greece
2Faculty of Sport and Physical Education, University of Belgrade, Serbia

The purpose of the present study was to compare the blood lactate concentrations after two tests of maximal intensity: a) 2x100 freestyle swimming and b) 4x50m freestyle. Eight competitive swimmers participated in this study. Capillary blood samples were obtained the 3rd, 5th and 7th min after the end of each test. Analysis of the results showed that there is a statistically significant correlation between the lactate concentration in the test of 2x100 and 4x50m freestyle swimming only for females (r=0.871). Moreover, no statistical significance was observed between the test of 4x50 or 2x100 concerning lactic acid accumulation between male and female. The results obtained showed that the tested female swimmers swim at 4x50m more efficiently than their male counterparts.

Key words: Freestyle swimming, maximum lactate concentration, gender

INTRODUCTION
Lactic acid constitutes a useful tool for the determination of anaerobic capacity for researchers and trainers. The highest lactate levels have been recorded following the swimming distances of 100 and 200 meters (Avlonitou 1996). The energy cost of swimming has been found to depend on the drag of the athlete, efficiency of stroke mechanics and velocity of movement through the water. Competitive swimming requires intense activity from a large muscle mass. This requirement favours involvement of anaerobic energy release with the subsequent accumulation of lactate in the blood.

The measurement of blood lactate concentration has become a common practice of swimming coaches for performance diagnosis and training control in competitive swimming over the last few years (Pelayo et al. 1996; Avlonitou, E. 1996). For researchers and coaches, lactic acid constitutes a useful implement for the determination of anaerobic capacity. Lactic acid is a useful marker of anaerobic capacity for researchers and trainers. Considerable emphasis has been given to the measurement of blood lactate during sub-maximal and maximal swimming efforts. Muscle lactic levels are between 1 – 2 mmol/l in the blood during rest and can increase to between 10 -20 mmol/l during all out effort (Maglischo 2003). The distances that are used to measure maximum lactic acid accumulation are 100m or 200m (Avlonitou, E. 1996). As a result, for the maximum production of lactic acid, efforts of 1 to 2 minutes of full intensity are required. Rate of lactic acid production in muscle fibers depends on swimming speed, rate of oxygen consumption and type of muscle fiber (Maglischo 2003). There is much interest concerning difference in blood lactate accumulation level in male and female swimmers.

Indeed, several studies have used the relationship between blood lactate concentration and swimming velocity to determine the appropriate exercise intensities during competition (Sawka et al. 1979; Chatard et al. 1988) or training and to gauge swimmers adaptation to training programs (Mader et al. 1978; Keskinen et al. 1989; Ryan et al. 1990; Costill 1992).

In their attempt to improve competition performance, swimmers perform large volumes and/or high intensities of training with, sometimes, insufficient time to recover between workouts (Pelayo et al. 1996). There is little information for the comparison of different maximum efforts in order to determine the most adequate training method for maximal accumulation and tolerance of lactic acid.
In addition, review of the scientific literature revealed that peak blood lactate levels are not significantly different between sexes, suggesting that the capacity to produce high lactate levels in the blood is probably acquired through training, rather than being sex related (Chatard et al. 1988; Jacobs et al. 1983).

The success in these tests seems to depend on the swimmer's capacity to achieve higher velocities with lower blood lactate levels and/or utilizing a lower percentage of their VO2 max. (Ribeiro 1990).

The purpose of the present study was to compare two specific tests for the determination of maximum accumulation of lactic acid in blood, based on two distances of 2x100m and 4x50m freestyle of maximum intensity and the same rest, comparing: a) the two tests and b) the two genders.

METHODS
In the present study 8 swimmers of competitive level participated (4 males of 16.2±0.96 years, body mass 71.70±5.56kg and body stature 181.12±7.86cm and 4 females of 15.5±2.08 years, body mass 53.27±14.92kg and body stature 164.87±9.20cm). At the beginning, they swam 2x100 meters freestyle with maximum intensity and time performance and the blood lactate accumulation was measured. Five days later the same athletes were tested for 4x50 meters with 10 seconds rest between each effort of 50 meters. In order to determine maximum concentration of lactic acid in the two different tests, capillary samples of blood were taken from the finger of 3rd, 5th, 7th and 10th minute of recovery time and analysed using the automatic analyzer Lactate Scout. For the comparison of mean values of blood lactate production in the two tests, the t-test for dependent samples was applied. Furthermore, the correlation coefficient was examined between the two tests.

RESULTS
The average time performance of swimmers in 2x100 meters freestyle was 120.79±5.67 sec and 146.32±5.26 sec while in 4x50 m it was 120.43±5.96 sec and 139.64±5.44 sec in males and females respectively. Maximum accumulation of lactic acid in 2x100 meters freestyle was 11.3±2.6 and 10.3±2.1 mmol/l in males and females respectively. In relation to the test of 4x50 it was 12.1±2.3 and 12.5±3.9 mmol/l in males and females, respectively. Significant correlation was found between the two tests in lactic acid accumulation only among the females (r=0.871; p<0.05). Statistically significant greater accumulation of lactic acid was observed in females 12.5±3.9 than males, 10.3±2.1 at the test of 4x50 freestyle swimming, while no statistically significant difference was observed for the test of 2x100 meters. Descriptive statistics and t - test were used for the statistical analysis.

DISCUSSION
With the application of this procedure, when comparison for differences of peak lactate values in 3rd, 5th and 7th min post-exercise was performed for these two tests, significantly greater correlation was demonstrated for females in 4x50m freestyle. This leads to a definition of a test for the swimmers at 4x50m free-style, which will be further used to improve the technology of swimmers' sport training. Since lactate measurement is specific to the type of activity used, training specificity should also be orientated for the athletes (Avlonitou 1996). The results obtained showed that the tested female swimmers of this study swim 4x50m achieving higher levels of lactic acid than their male counterparts.

Lactate production could also be influenced by the difference in swimming ability among athletes. Swimming performance was significantly related to peak lactate levels for the distance of 2x100m (r=0.359).

Another factor that can affect blood lactate concentration during maximal effort is muscle mass of the subjects (Avlonitou 1996). However, body composition analysis was not examined in this study, thus it was not possible to check the effects of muscular mass on performance and blood lactate.

CONCLUSION
In the present study the female swimmers tested achieved higher levels of lactic acid at 4x50m freestyle than their male counterparts. However aHsd number of different physiological factors can play a role in the production and removal of lactate and consequently to its relationship to performance, assuming that the athlete is highly motivated during the event.

REFERENCES
Can Blood Glucose Threshold be Determined in Swimmers Early in the Swimming Season?

Sengoku, Y. ¹, Nakamura, K. ², Takeda, T. ³, Nabekura, Y. ², Tsukamoto, S. ²

¹Heisei International University, Saitama, Japan
²University of Tsukuba, Ibaraki, Japan
³University of Fukui, Fukui, Japan

The present study investigated whether blood glucose threshold (GT) could be determined in swimmers early in the swimming season. Seven university swimmers participated in this study and performed an incremental swimming test in a swimming pool. The test was conducted 4 – 5 weeks after the winter season commencement. Blood glucose (Glu) and blood lactate (Bla) were measured after each swimming incremental step, and the velocity corresponding to GT and blood lactate threshold (LT) was calculated. A LT was observed in all swimmers. However, Glu tended to decrease as the test started and then did not increase with swimming intensity. The low Glu observed during high intensities may be due to high glucose uptake by the working muscles or low endurance capacity in the early season. A GT could not be observed for all swimmers.

Key words: endurance capacity, incremental swimming test, glucose metabolism

INTRODUCTION

Blood lactate concentration (Bla) is known to increase rapidly at high exercise intensity during an incremental test and the exercise intensity where Bla starts to rise is recognized as lactate threshold (LT). LT is observed when lactate production surpasses the lactate removal rate and thus this intensity is considered to demonstrate the boundary of aerobic and anaerobic energy supply and is utilized as an indicator of aerobic endurance performance (Hollman, 1985).

Recently, Simões et al. (1999) reported that blood glucose (Glu) also increases during an incremental running test and a blood glucose threshold (GT) could be observed as for LT. It was reported that GT significantly correlates with LT, ventilation threshold (VT) and maximal lactate steady state (MLSS) (Simões et al., 1999; Simões et al., 2003; Sotero et al., 2009), thus GT may also be a good indicator for the aerobic-anaerobic transition.

Simões et al. (1999) speculated that the increase of Glu when exercise became more intense was due to activated catecholamine and glucagon responses. It is considered that these hormonal activities will elevate when the exercise intensity rises above the anaerobic threshold (AT) and higher glucose production than glucose uptake by the skeletal muscle may lead to a Glu increment. For these reasons, it could be suggested that Glu reflects the shift of glucose metabolism and the GT could be a new index for energy metabolism during endurance exercise. However, observations of GT were reported only in running (Simões et al., 1999; Simões et al., 2003; Sotero et al., 2009) and cycling (Júnior et al., 2001) and there is no study investigating GT in competitive swimmers whose endurance capacity is supposed to be important. As a previous study reported that Glu is lower in swimming than running after sub-maximal continuous exercise (Flynn et al., 1990), there are possibilities that different Glu response may occur even during incremental exercise.

The purpose of the present study was to investigate Glu response during an incremental swimming test and verify whether GT could be determined as in running on land early in the swimming season.

METHODS

Seven male university swimmers specialized in middle and long distance freestyle (n = 3) or individual medley (n = 4) participated in this study (20.1 ± 0.9 years of age, 173.1 ± 4.3 cm height, 65.2 ± 2.6 kg body weight, 4.021 ± 0.8 for best 400 m freestyle). All swimmers were competing at national level championships. The measurement was conducted 4 – 5 weeks after the winter season commencement (Nov. 2009). The subjects were made fully aware of the risks, benefits and stresses of the study and their informed consent was obtained.

All incremental swimming tests were conducted in a swimming pool at University of Tsukuba. The schematic representation of the testing is presented in Fig. 1. Swimming velocity of the incremental swimming test was individualized by each swimmer’s average swimming speed for their best 400 m freestyle (V400). After a 5 min warm up at 55% V400 and a 4 min rest, the participants completed an incremental swimming test consisting of a series of seven 3 min swimming steps with 2 min interval for blood sampling. The intensity of each step was increased from 55% to 85% V400.

![Fig. 1 Schematic representation of the testing sequence](image1)

Before the test and right after each incremental swimming step, blood samples were obtained from the finger tip and blood glucose (Glu; Glucose Oxidase/Glucose Dehydrogenase, GT-1670, Arkray, Japan) and blood lactate (Bla; Lactate Pro, LT-1710, Arkray, Japan) were measured. The accuracy of the portable measurement devices are assessed in previous studies (Weitgasser et al., 1999; Tanner et al., 2010). Swimming velocity corresponding to GT (VGT) and LT (VL T) were analyzed utilizing Blood Lactate Endurance Marker Software (Lactate-E) (Newell et al., 2007).

The subjects were instructed to refrain from strenuous physical activity and caffeine intake on the testing day and finish their last meal 3 h before testing. Only water ingestion was allowed after the final meal. All data are reported as mean ± SD.

RESULTS

Glu and Bla before the test were 5.5 ± 0.8 mmol/l and 1.2 ± 0.4 mmol/l respectively. Result of the Glu and Bla measurements during the incremental swimming test are presented in Fig. 2. LT was observed in all swimmers and the average VLT was 1.24 ± 0.05 m·sec⁻¹. Glu tended to decrease as the test started and did not increase at the higher swimming intensity steps. Consequently, a GT threshold could not be determined for all swimmers.

![Fig. 2 Blood glucose and blood lactate responses during incremental swimming test](image2)
DISCUSSION
The present study intended to investigate Glu response during an incremental swimming test and verify whether GT could be determined early in the swimming season. The main finding of this study was the constant Glu level throughout the incremental swimming test and that GT was not observed in competitive swimmers. The subjects in this study trained on a daily basis as they were elite national level competitive swimmer. The physical activity preceding this investigation was not controlled for, which is a limitation in this study. However, physical activity level and nutritional state were controlled on the testing day and the resting Glu and Bla were at a normal level (5.5 ± 0.8 mmol·l⁻¹ and 1.2 ± 0.4 mmol·l⁻¹, respectively).

Previous studies reported that GT was observed during an incremental running test on land and GT significantly correlates with LT, VT and MLSS (Simões et al., 1999; Simões et al., 2003; Sotero et al., 2009). The possible mechanism for the GT observation is speculated to be affected by the activated catecholamine and glucagon responses, thus the different hormonal response between swimming and running could explain the conflicting results in this study. Unfortunately, running and hormone measurements were not performed in the present study.

Flynn et al. (1990) investigated the Glu response during 45 min of swimming or running (75% VO₂max) and reported that a lower Glu level was observed after swimming than running. In addition, this study demonstrated that epinephrine levels was similar after both trials. However, the Glucagon to Insulin ratio (G:I ratio) was significantly higher for swimming than running. Greater glucagon to insulin ratio represents higher hepatic glucose production, therefore, it is suggested that the energy demand of hepatic glycogen at the same relative exercise intensity may differ between swimming and running.

An increased reliance on carbohydrate during swimming is also discussed in the work of Lavoie (1982). It is speculated that swimming may result in a preferential recruitment of type II fibers and thus increase the dependence on glycolytic processes. Considering these studies, it is possible that glucose uptake was higher during the incremental swimming test than in running and Glu did not increase at the higher intensity steps in the present study. Further investigation is needed to examine carbohydrate oxidation and hormonal response during an incremental swimming test to clarify the mechanism of the different Glu responses in swimming.

On the other hand, the swimmer’s training state during this investigation may be another factor causing Glu not to increase along with exercise intensity increment. Coggan et al. (1995) investigated the Glu response during 30 min at 80% VO₂max cycling comparing endurance trained cyclists and untrained subjects. They reported that rate of glucose disappearance during exercise was 19% lower in the trained compared with the untrained subjects (27.0 ± 2.6 vs. 33.2 ± 1.5 mmol·min⁻¹·kg⁻¹; p < 0.001), consequently, during exercise, plasma glucose concentration rose significantly in the trained subjects but did not change in the untrained subjects. Thus, observation of GT during an incremental exercise test may reflect the endurance capacity level of the subject. The present study was conducted 4 – 5 weeks after the winter season commencement. Before the season, all subjects spent a one month resting period, so it could be that the endurance capacity of the present subject was not highly enhanced. As there is no study investigating the effect of endurance training on GT, further study is warranted to examine Glu response during an incremental swimming test at higher levels of endurance, later in the season.

CONCLUSION
The present study intended to investigate Glu response during an incremental swimming test and verify whether GT could be determined early in the swimming season. It was clarified that GT could not be determined during an incremental swimming test. The fact that Glu did not increase was speculated to be the different hormonal response during swimming or the effect of the measurement period when swimmer’s endurance capacity was not highly enhanced. Further research is needed to clarify the Glu response during an incremental swimming test by analyzing the physiological responses more precisely.

REFERENCES
The Effects of Rubber Swimsuits on Swimmers Using a Lactic Acid Curve Test

Shiraki, T., Wakayoshi, K., Hata, H., Yamamoto, T., Tomikawa, M.

1Biwako Seikei Sport College, Japan
2YAMAMOTO CORPORATION CO., LTD., Japan
3University of Tsukuba, Japan

The rubber swimsuit, made from Neoprene rubber, was one of the causes of the swimming record rush in 2009. The benefits of wearing a wetsuit on swimmers were widely reported. This study verified the influence of wearing the rubber swimsuit on a swimming exercise load. Eight female university swimmers performed 4 x 200 m crawl swimming at incremental speeds, set from the best record of each 200 m freestyle race (80%V\text{200}, 85% V\text{200}, 90% V\text{200}, 95% V\text{200}). Four different suits (three types of rubber suits and a cloth swimsuit) were used and lactic acid curve tests were conducted. The blood lactate concentration after 90% V\text{200} and 95% V\text{200} trials with rubber swimsuits tended to be lower than those with a cloth swimsuit. An examination of the trials revealed that the total number of arm strokes tended to decrease due to the use of the rubber swimsuits. It is suggested that the rubber swimsuits might improve propulsion efficiency and decrease the swimmer’s exercise load, indicating that the rubber swimsuit may improve the race performance of swimmers.

Key words: rubber swimsuit, Lactic acid curve test

INTRODUCTION

Forty-three new world records were set in 13th FINA World Championships in Rome 2009. It was not just a historical coincidence that the 43 new world records were established in just one meeting. These records were reached with new swimsuits with high technology. In fact, the rubber swimsuit was one of the causes of this record rush. Being similar to wetsuits, the rubber swimsuit was made from Neoprene rubber. So, rubber swimsuits probably present beneficial characteristics similar to wetsuits. The effects of using wetsuits on swimmers were widely reported: (i) triathletes are able to hold their bodies in a more horizontal position because of the added buoyancy (Chatard et al., 1995, Toussaint et al., 1995, Toussaint et al., 1989) and (ii) drag force is reduced by the position because of the added buoyancy (Chatard et al., 1996, Chatard et al., 1989). This study aimed to verify the influence of wearing a rubber swimsuit on the swimming exercise load by using a lactic-velocity curve test.

METHODS

Eight female university swimmers participated in this study. The average of their best records for 200 m freestyle swimming was 129.8 ± 4.5 seconds. They attended the Japanese inter-college swim meet 2009. Their age, height and weight were 19.8 ± 0.9 years, 160.8 ± 4.2 cm and 58.0 ± 2.8 kg, respectively, and they had a body fat % of 28.4 ± 3.6.

Four types of suits were used in this study. Three rubber suits were made from Neoprene rubber: (i) rubber suit A was a commercially available suit; (ii) rubber suit B was made from Neoprene rubber, and metallic minerals were contained between rubber and back fabric layers; (iii) rubber suit C was also made from Neoprene rubber, in which titanium was included in bond part between rubber and back fabric layers. Rubber suit B and C were not commercially available. The 4th suit type was a cloth swimsuit, being a common water-repellent competitive swimsuit. All swimsuits were the full-length type, covering from shoulder to ankle.

Swimmers performed a 4 x 200 m incremental swimming protocol, the speed of the four stages set from the best record of each 200 m freestyle race (80%V\text{200}, 85% V\text{200}, 90% V\text{200}, 95% V\text{200}). The speed was controlled by a pace maker set on the bottom of pool. Blood from the fingertip was taken at 0, 3 and 5 min after each trial. The blood lactate concentration was determined using Lactate Pro analyzer (ARKRAY, Inc.). Arm strokes in the trials were counted each 25 m (LAP 1 to 8).

The mean and standard deviation were computed for all variables. ANOVA with repeated measures was used to compare the data obtained in the wetsuits and a swimsuit condition. A probability level of 5% was selected for tests of statistical significance.

RESULTS

The mean ± SD values of blood lactate concentrations in each trial are shown in Table 1. No significant differences were found in blood lactate concentration between different rubber suit conditions.

![Fig 1. The blood lactate concentration-Swimming velocity curve in an experimental suits conditions](image)

Table 1. Means ± SD of Blood lactate concentration in each suit condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>NS mmol·L⁻¹</th>
<th>RS-A mmol·L⁻¹</th>
<th>RS-B mmol·L⁻¹</th>
<th>RS-C mmol·L⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>80%V\text{200}</td>
<td>1.49 ± 0.45</td>
<td>1.61 ± 0.54</td>
<td>1.54 ± 0.51</td>
<td>1.30 ± 0.47</td>
</tr>
<tr>
<td>85%V\text{200}</td>
<td>2.11 ± 0.59</td>
<td>1.95 ± 0.88</td>
<td>1.83 ± 0.69</td>
<td>1.78 ± 0.61</td>
</tr>
<tr>
<td>90%V\text{200}</td>
<td>3.89 ± 1.37</td>
<td>3.20 ± 1.73</td>
<td>2.89 ± 1.21</td>
<td>2.95 ± 1.45</td>
</tr>
<tr>
<td>95%V\text{200}</td>
<td>10.46 ± 2.37</td>
<td>8.68 ± 2.66</td>
<td>9.35 ± 2.24</td>
<td>8.18 ± 2.98</td>
</tr>
</tbody>
</table>

However, the blood lactate concentration after 90% V\text{200} and 95% V\text{200} trials with rubber swimsuits tended to be lower than those with a cloth swimsuit (Figure 1). Especially, when wearing rubber suit C, the blood lactate concentration tended to be lower than wearing other suits. The blood lactate concentrations after 90% V\text{200} and 95% V\text{200} trials with the four suits were at the same level.
The trials were controlled by a pace maker. When wearing rubber swimsuits, most subjects could swim 2.0–2.9% faster than the velocity (95% V200) trials set by the pace maker (Fig.1, Table 2).

### Table 2. Means and Standard Deviations of Swimming velocity in each suit condition

<table>
<thead>
<tr>
<th>Suit Condition</th>
<th>m·s⁻¹</th>
<th>RS-A</th>
<th>m·s⁻¹</th>
<th>RS-B</th>
<th>m·s⁻¹</th>
<th>RS-C</th>
<th>m·s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>80%V200</td>
<td>1.24±0.04</td>
<td>1.25±0.04</td>
<td>1.25±0.04</td>
<td>1.25±0.04</td>
<td>1.25±0.04</td>
<td>1.25±0.04</td>
<td>1.25±0.04</td>
</tr>
<tr>
<td>85%V200</td>
<td>1.32±0.04</td>
<td>1.32±0.04</td>
<td>1.32±0.05</td>
<td>1.32±0.05</td>
<td>1.32±0.05</td>
<td>1.32±0.05</td>
<td>1.32±0.05</td>
</tr>
<tr>
<td>90%V200</td>
<td>1.39±0.05</td>
<td>1.40±0.05</td>
<td>1.40±0.05</td>
<td>1.40±0.05</td>
<td>1.40±0.05</td>
<td>1.40±0.05</td>
<td>1.40±0.05</td>
</tr>
<tr>
<td>95%V200</td>
<td>1.49±0.04</td>
<td>1.50±0.04</td>
<td>1.51±0.06</td>
<td>1.51±0.06</td>
<td>1.51±0.06</td>
<td>1.51±0.06</td>
<td>1.51±0.06</td>
</tr>
</tbody>
</table>

No significant differences were found in the number of arm strokes per 25m between suit conditions. Conversely, an examination of the trials revealed that the total number of arm strokes tended to decrease due to the use of rubber swimsuits in 90%V200 and 95%V200 swimming (Fig.2 and 3).

**Fig 2. The total number of arm strokes in 90% V200 swimming in different suit condition**

**Fig 3. The total number of arm strokes in 95% V200 swimming in different suit condition**

### DISCUSSION

No significant differences were found in blood lactate concentration between the suit conditions. However, Figure 1 shows that the blood lactate concentration after 90% V200 and 95% V200 trials with rubber swimsuits tended to be lower by 1.1 to 2.2 mmol·L⁻¹ than those with a cloth swimsuit. Even though the swimming velocity was controlled by a pace maker on the bottom of the pool, some subjects could swim faster at 90% V200 and 95% V200 trials with rubber swimsuits. The results suggested that wearing rubber swimsuits might improve the propulsion efficiency and reduce anaerobic energy consumption at a comparable swimming velocity. In previous studies, it was assumed that wearing a wetsuit might reduce the exercise intensity during swimming (Bentley et al., 2002). Tomikawa et al. (2008) reported that even if triathletes have similar VO₂max in the wetsuit and swimsuit conditions, they swam 5.4% faster with a wetsuit. Given this result, it was considered that the effects of wearing a rubber swimsuit were similar to those of wearing a wetsuit, although a rubber swimsuit was thinner than a wetsuit.

When wearing a wetsuit, since triathletes float in a more horizontal position because of the added buoyancy, they are able to devote more energy to their arm propelling motion, and to increase their stroke rates with lengthening or retaining stroke lengths (Chatard et al., 1995, Tomikawa et al., 2003). In this study, an examination of the trials revealed that the total number of arm strokes tended to decrease due to the use of the rubber swimsuits (Figs. 2 and 3), while no significant differences were found in the total number of arm strokes between the suit conditions. It was suggested that swimmers could devote more energy to the propulsive force because of the added buoyancy, when wearing rubber swimsuits.

### CONCLUSION

The results showed that the beneficial characteristics of rubber swimsuits might be similar to those of wetsuits. Since rubber swimsuits were thinner than wetsuits, the effects of wearing a rubber swimsuit on swimmers were obviously smaller. Therefore, it is suggested that the rubber swimsuits might improve the propulsion efficiency and reduce the exercise intensity during swimming, indicating that the rubber swimsuit may improve the race performance of swimmers.

### REFERENCES


Some Factors Limiting Energy Supply in 200m Front Crawl Swimming

Strumbelj, B., Usaj, A., Kapus, J., Bednarik, J.

University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia

The aim of this research was to establish whether any measured factors could limit energy supply on 200 m front crawl swimming. Twelve male swimmers performed 4 swims of 200 m crawl at intensities of 80%, 90%, 100% and 110% (until exhaustion) on separate days with a swimming snorkel. Respiratory parameters (VE, VO2), blood parameters (pH, [LA-]) and heart rate (HR) were measured. The results demonstrate that limitations in V E, VO2 and HR during swimming occur during supra maximal swimming (no further increase of measured maximal parameters and time constant parameters) in comparison to maximal swims. Limitations in obtained maximal [LA-] and minimal pH values were found. It is possible to conclude that individual limitations in V E, VO2, HR and consequently acidosis could be limiting factors of individual performance on 200 m front crawl because of energy supply limitations.

Key words: swimming, front crawl, energetics, maximal, supra maximal performances

INTRODUCTION

Maximal performances in swimming depend on the maximal metabolic power of the athlete and on the economy of locomotion. The amount of metabolic energy spent in transporting the body mass of the subject over a unit of distance has been defined as the energy cost of locomotion (di Prampero, 1986). Energy during swimming is estimated as the sum of the energy derived from anaerobic (AnAL), aerobic (AnAL) and anaerobic (Aer) processes. The amount of metabolic energy spent during supra maximal swims (E, kilojoules) was assumed to be the sum of three terms:

\[ E = E_{an} + \alpha V_{O2max} t_p + \alpha V_{O2max} \pi (1 - e^{-t_p / \tau_p}) \]

where \( \alpha \) is the energy equivalent for O2, assumed to be equal to 20.9 kJ·l-1, \( \pi \) is the time constant for the attainment of \( V_{O2max} \) from the onset of exercise, \( E_{an} \) is the amount of energy derived from the use of anaerobic energy stores, \( t_p \) is the performance time, and \( V_{O2max} \) (litres per second) includes \( V_{O2} \) at rest (Capelli et al. 1998). Energy cost of swimming with different intensities (± SD)

\[
\begin{align*}
\text{VE (l.min)} & \quad 78.18±13.49 & 91.43±13.61 & 117.40±17.98 & 108.72±17.19 \\
\text{VO2 (l.min)} & \quad 3.09±0.51 & 3.44±0.49 & 3.81±0.51 & 3.70±0.51
\end{align*}
\]

VE increased at intensities ranging from 80% (78.2±13.5 l.min) to 100% (117.4±18 l.min) (p<0.05), but at 110% intensity it was similar to the values at 100% intensity. Something similar happened with VO2 (80% = 2.65±0.5 l.min, 100% = 2.76±0.6 l.min) (p<0.05). Between 100% and 110% intensity there were no differences.

METHODS

Twelve male swimmers (age: 24 ± 3 yrs; height: 181 ± 9 cm; body mass: 77 ± 13 kg) volunteered to participate in this study. All subjects had a minimum of eight years competition swimming experience and considered front crawl their best stroke. The subjects were informed of the risks involved in the experiment before they agreed to participate.

All swims were performed using the front crawl stroke in a 25 m indoor swimming pool. The temperature of the water was 27° C. Each swimmer performed 4 swims of 200 m crawl at intensities of 80%, 90%, 100% and 110% (until exhaustion) on separate days with a swimming snorkel (Toussaint et al. 1987). First, the swimmers performed a maximal 200 m front crawl swim. Thereafter, they performed sub/maximal swims with 80% and 90% of maximal 200 m front crawl velocity. Finally, the swimmers performed a supra-maximal swim with 110% velocity until exhaustion (on average they were able to swim 113.8 ± 17.0 m)...

A light leader was used to keep even pace during swimming with sub-maximal and supra-maximal intensities.

Arterial blood samples (20 µl) were collected from the earlobe after a warm up and at 1, 3 and 5 minutes of recovery after swimming and analyzed for blood lactate concentration ([LA-]) using a Kodak Ektachrome analyzer. At the same time, arterial blood samples (60 - 80 µl) were collected and analyzed for pH with an ABL5 analyzer (Radiometer Copenhagen). Calibration of the equipment was performed every six samples with standard lactate and pH solution, respectively. Maximal measured [LA-] and minimal pH obtained values were analyzed.

Ventilation (VE) and O2 uptake (VO2) were measured using a portable respiratory gas analyzer METAMAX 2 (Cortex, Germany) adapted to measurements with a swimming snorkel made by Toussaint et al. (1987). Average data for 10-s period were recorded after warm up, during swimming and 5 minutes after the end of each swim. The flow meter was calibrated with a syringe of known volume (3.0 l). The gas analyzer was calibrated by known standard gases.

Heart rate (HR) was measured using heart rate monitors POLAR S-610 (Polar, Finland). Average data for 10-s period were recorded after warm up, during swimming and 5 minutes after the end of each swim. From all obtained data of heart rate values in the rest were excluded to observe relative change.

Means and standard deviations were computed for all variables. Individual one-way repeated measures ANOVA's were employed to test for any significant differences between the measured parameters. Significance was accepted when p<0.05. Bonferroni's post-hoc tests were performed if significant differences were apparent.

RESULTS

Table 1: average maximal measured values of VE and VO2 during swimming with different intensities (± SD)

<table>
<thead>
<tr>
<th>Intensity</th>
<th>VE (l.min)</th>
<th>VO2 (l.min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80% load</td>
<td>78.18±13.49</td>
<td>3.09±0.51</td>
</tr>
<tr>
<td>90% load</td>
<td>91.43±13.61</td>
<td>3.44±0.49</td>
</tr>
<tr>
<td>100% load</td>
<td>117.40±17.98</td>
<td>3.81±0.51</td>
</tr>
<tr>
<td>110% load</td>
<td>108.72±17.19</td>
<td>3.70±0.51</td>
</tr>
</tbody>
</table>

Figure 1. VE kinetic responses of interpolated data to value of 0 l.min⁻¹ during swimming with different intensities to the moment when all swimmers were able to perform the predefined load.
With ANOVA significant changes were found between interpolated values of \( V_{E} \) from 10 to 80 seconds (p<0.05). A significant difference between \( V_{E} \) at 80% intensity and \( V_{E} \) at 110%, from 10 to 80 seconds (p<0.05) was found using post hoc tests. \( V_{E} \) values at 80 seconds were found to be different between 90% and 110% intensities and 110% intensity values (p<0.05).

With ANOVA significant changes were found between interpolated values of \( V_{E} \) from 10 to 80 seconds (p<0.05). Significant differences between \( V_{E} \) at 80% intensity and \( V_{E} \) at 110% (p<0.05) were found with the post hoc test. \( V_{E} \) values at 80 seconds were different between 90% and 110% intensities and 110% intensity values (p<0.05).

With ANOVA significant changes were found between interpolated values of \( V_{E} \) from 20 to 80 seconds (p<0.01). Significant differences between \( V_{E} \) at 80% intensity and \( V_{E} \) at 110% (p<0.05) were found with the post hoc test. \( V_{E} \) values at 80 seconds were different between 90% and 110% intensities and 110% intensity values (p<0.05).

Table 2.: average maximal obtained values of \( pH \) and \([LA-]\) during swimming with different intensities (± SD)

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>10 % load</th>
<th>20 % load</th>
<th>30 % load</th>
<th>40 % load</th>
<th>50 % load</th>
<th>60 % load</th>
<th>70 % load</th>
<th>80 % load</th>
<th>90 % load</th>
<th>100 % load</th>
<th>110 % load</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.34 ± 0.03</td>
<td>7.33 ± 0.03</td>
<td>7.31 ± 0.04</td>
<td>7.30 ± 0.04</td>
<td>7.29 ± 0.05</td>
<td>7.29 ± 0.04</td>
<td>7.28 ± 0.05</td>
<td>7.28 ± 0.04</td>
<td>7.28 ± 0.05</td>
<td>7.28 ± 0.04</td>
<td>7.28 ± 0.05</td>
</tr>
<tr>
<td>[LA-] (mmol/l)</td>
<td>5.7 ± 0.1</td>
<td>6.1 ± 0.1</td>
<td>7.4 ± 0.1</td>
<td>7.8 ± 0.1</td>
<td>12.7 ± 0.6</td>
<td>14.2 ± 0.6</td>
<td>9.9 ± 0.1</td>
<td>12.0 ± 0.1</td>
<td>11.1 ± 0.1</td>
<td>11.3 ± 0.1</td>
<td>11.0 ± 0.1</td>
</tr>
</tbody>
</table>

The most notable change of HR was from 90% (165±10 b.min⁻¹) to 100% (177±11 b.min⁻¹) intensity (p<0.05). Between 100% and 110% intensity there were no significant differences.

With ANOVA significant changes were found between interpolated values of heart rate from 10 to 60 seconds (p<0.01). A significant difference between HR values at 80% intensity and HR values at 100% and at 110% intensity (p<0.01) were found using post hoc tests. No changes were found between HR values at 100% and 110% intensity.

DISCUSSION

The energy cost of swimming at velocities ranging from moderate in which metabolism was almost completely aerobic, to maximal over competition distance was studied in the past by many researchers (Holmer 1974; Monpetit et al. 1988; Toussaint et al. 1988; di Prampero 1986; Capelli et al. 1998; Zampero et al. 2005). The energy cost of swimming increases as a function of the speed and it depends among other things upon swimming style, the technical skill of the swimmer, the gender, the anthropometric features of the swimmer, the individual buoyancy, passive and active drag and propelling efficiency (Zampero et al. 2000). The aim of our study was not to estimate energy cost of front crawl swimming at different speeds of swimming but to establish whether any of the energy supply system could potentially be a limiting factor for the maximal performance on 200 m front crawl swimming. Since the anaerobic lactic system could be considered as a stable system to provide energy, the focus was on anaerobic lactic and aerobic processes. From our results it is visible that with increasing intensity of swimming, \( V_{E} \) and \( V_{O2} \) increases from 80% intensity to 110% intensity, when \( V_{E} \) and \( V_{O2} \) kinetics were observed during swimming at different intensities. However when comparing maximal obtained values of both parameters, swimmers were found not to be able to swim at 110% intensity when similar values of that at 100% intensity.
were reached (Table 1). Something similar was observed with maximal heart rate values (Table 3). Additionally, kinetics of HR frequency was similar at 110% intensity to that at 100% intensity (Figure 4). From our results it could be concluded that the aerobic energy supply to working muscles could be limited by the cardiovascular system at supra-maximal intensities (no further increase of maximal heart rate and kinetic responses of heart rate). However at the beginning of the swimming, swimmers were able to compensate the insufficient energy supply by aerobic processes with increased energy production by anaerobic lactic processes, since increased lactate production per unit of time was found with increasing intensity of swimming (Figure 3). However when the level of acidosis and lactate concentration at 110% intensity was similar to that at 100% intensity swimmers were no longer able to swim at that intensity (Table 2). From the results it was not possible to demonstrate that insufficient energy supply is the limiting factor of maximal performance in front crawl swimming. However when certain levels of $V_{E}$, $V_{O_2}$, HR, pH and lactate concentration were reached, similar to those at maximal intensity, swimmers were no longer able to swim at selected supra-maximal intensity.

**CONCLUSION**

The energy cost of swimming increases as a function of the speed. With increase of swimming speed the sum of energy supply during swimming should increase from either alactic (AnAl), lactic (AnL) and aerobic (Aer) processes. It is concluded that insufficient energy supply because limitations in aerobic and anaerobic lactic processes occur, could limit the maximal speed of swimmers for 200 m front crawl.

However there is still the open question as to whether the swimmers studied need more aerobic training or do they need more anaerobic training to better their performances in the 200 m front crawl or do they need to improve their swimming technique.

**REFERENCES**


---

**Lactate Comparison Between 100m Freestyle and Tethered Swimming of Equal Duration**

Thanopoulos, V., Rozi, G., Platanou, T.

*Faculty of Physical Education and Sports Science, University of Athens, Greece*

The purpose of the present study was to compare the blood lactate concentrations after two tests of maximal intensity: A) 100m freestyle swimming and B) tethered swimming of equal duration with the test of 100m freestyle. Furthermore, the force produced in tethered swimming was measured. Twelve male competitive swimmers participated in this study. Capillary blood samples were obtained 3’, 5’ and 7’ min after the end of each test. Analysis of the results showed that there was no statistically significant difference between the lactate concentrations in the tethered swimming test and the test of 100m freestyle swimming. Moreover, there was correlation between performance in 100 m and force in tethered swimming ($r = 0.63$). The results indicate that when tethered swimming is used for sprinters, it seems more adequate to analyze the values of mean force because as a mechanical characteristic, it better describes sprinters achievements.

**Keywords**: blood lactate, pulling force, freestyle sprinters, swimming performance

**INTRODUCTION**

Maximal swimming velocity, especially at sprint distances, except for technical ability depends on pulling force characteristics and maximal anaerobic lactic capacity that is proportional with maximum production of lactic acid. In order to determine maximum lactate accumulation, several middle distance tests are used as well as resistance swimming. The most common test for anaerobic capacity is 100m freestyle. Several researchers have also used tethered swimming. The test most widely used to measure pulling force realized in swimming is the tethered swimming test (Keskinen et al., 1988; Sidney et al., 1996; Maglischo, 2003). Furthermore, tethered swimming is one of the most famous types of training for swimmers and aims at increasing maximum speed and strength (Maglischo, 2003). The subject wears a special belt and swims at the same point (tethered swimming Bonen et al., 1980). Viewed kinematically, swimming is a series of cyclic movements performed by alternation of arm and leg strokes. Each stroke results in a characteristic force, which pulls the swimmer forward and is realized by contracting the muscles involved.

Many researchers suggested this mean of training that helps in increasing maximum speed and improving strength for better preparation of swimmers. (Colvin; 1993; Counsilman, 1979; Hannula, 1995; Smith, 2002; Maglischo, 2003).

Some other reviewers found positive correlation between swimming performance and muscular strength that can be measured in several ways (Sharp et al., 1982; Costill et al., 1983; Hawley & Williams, 1991; Crowe et al., 1999). Previous research has focused only on the relationship between the maximal pulling force or the average of maximal pulling forces (Fmax or avgFmax) of a single stroke realized in a time interval of 10 seconds, and the swimming velocity achieved mainly at sprint distances (Sidney et al., 1996, Dopsaj, 2000).

In terms of measurements, Fmax or avgFmax contains information solely about the force peak point or the average of such points achieved for the given single strokes realized by tethered swimming. On the other hand, force as a measurable value which is a product of muscular contraction is defined by at least two more dimensions, i.e., by its increment gradient/ its increment in time (RFD – rate of force development) and by the impulse of force (ImpF) (Zatsiorsky, 1995), the realization of which can be reliably measured in water during tethered swimming (Dopsaj, 2000).
Besides, the methodology of establishing the relationship and/or its quality between swimming velocity at a given distance and the characteristics of pulling force realized by tethered swimming requires that the test lasts at least approximately as long as the distance covered. In that way it is possible to adjust the observed occurrences, i.e., the characteristics of pulling force and the velocity of swimming (as criterion and predictor variables), also taking into consideration the load exerted on the same energy system (Ring et al., 1996).

According to previous research, the question that occurs is with which of the two events, 100m freestyle or tethered swimming of equal duration to 100m, maximum accumulation of lactic acid in blood can be achieved. Also, if there is a relationship between maximal performance in 100m freestyle swimming (the level of competitor fitness) and strength.

The purpose of this study was to examine lactic acid accumulation in blood after two efforts of maximum intensity and equal duration: a) 100m freestyle swimming and b) tethered swimming, as well as to find differences between these two measurements concerning lactate production and heart rate. Moreover, this study attempts to investigate the relationship between performance in 100m freestyle and the forces produced in tethered swimming. It was hypothesized that there are no significant differences in blood lactate accumulation after the two events.

METHODOLOGY

In this study 12 active swimmers of national level participated (age = 21.50±0.68 years, Body stature =182.83±7.24 cm and Body mass=80.75±8.00) in freestyle swimming (Table 1). At the beginning, they swam 100 meters freestyle with maximum intensity and time performance and blood lactate accumulation were measured. Samples of blood were taken at 3rd, 5th and 7th minute of recovery time and analysed immediately using the reflectance photometry - enzymatic reaction method (Accusport, Boehringer, Germany) in order to determine maximum accumulation of lactic acid in 100m freestyle swimming.

Two days later the same athletes were tested in tethered swimming, over an equal time to that achieved in the 100 meters swim. Blood samples were also taken in 3rd, 5th and 7th minute of recovery time in order to determine maximum lactate accumulation and strength characteristics were measured (Keskinen et al., 1989; Sidney et al., 1996), according to the standardized procedure (Dopsaj, 2000).

Table 1. Swimmers characteristics

<table>
<thead>
<tr>
<th>Male (N=12)</th>
<th>Age (years)</th>
<th>Body Stature (cm)</th>
<th>Body Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21.50±0.68</td>
<td>182.83±7.24</td>
<td>80.75±8.00</td>
</tr>
</tbody>
</table>

Before the test, the swimmers warmed up swimming independently up to 1000 m. After a 10-minute rest the measuring started. On his turn, each swimmer put on a belted harness adjusting it to his body dimensions (Figure 1). Then he hooked a 1cm-thick PVC rope to the belt at the back hip region. The other end of the 5m rope was attached to a water-resistant high-resolution (100 kHz) tensiometric dynamometer placed on a metal support fixed on the side of the pool (Figure 2). The dynamometer was connected to a PC. Having entered the pool, the swimmer did a 10-second trial of tethered swimming at medium intensity in order to get familiar with the equipment and the testing procedure. After a 1-minute rest the measuring commenced.

Fig. 1. Swimmer with the belted harness adjusting it to his body dimensions

The swimmers started tethered swimming (full technique – arms and legs stroke) at medium intensity and after two to three strokes, at the whistle of the timekeeper, they swam at maximal intensity for the same time as that achieved in 100m freestyle swimming. At the whistle, the assistant timekeeper, who operated the PC, started the program for measuring and acquisition of data. The raw data were processed by software specially designed by ProIng to analyze the parameters relevant to pulling force.

Fig. 2. The support with the dynamometer used to measure tethered pulling force

After the time of 100m freestyle there was a second whistle as the signal to stop swimming. This procedure yielded the entire recording of the pulling force during the achieved time of 100m freestyle. Swimmers were told to follow the breathing pattern they would normally apply during a race. The test was done in the indoor swimming pool of the Physical Education Faculty of Athens Kapodistrian University a week before the summer national senior championships.

All results are expressed as means and standard deviations. For the comparison of mean values of blood lactate production and of heart rate in the two tests, t-test with depended samples was applied. In addition, Pearson’s correlation coefficient was used to calculate the relationships between time of performance in 100m freestyle and strength produced in tethered swimming, as well as their relationship with lactic acid accumulation in both events. Statistical significance was set at p<0.05 for all analyses. For the statistical analysis the statistical logistic program STATISTICA 6.0 was used.
RESULTS
The performance time for 100m freestyle was 58.74±2.33, and was the time that they also swam in tethered swimming. The comparison in maximum accumulation of lactic acid and heart rate after the two tests are presented in table 2. Pared correlations showed that there were no statistical significant differences.

Table 2. Performance time, maximum blood lactate accumulation (mmol/l) and heart rate of swimmers after the tests.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Perf. time (sec)</th>
<th>Mean force (N)</th>
<th>Lactate (mmol/l)</th>
<th>Heart rate (beat/min)</th>
<th>P&lt;0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>100m freestyle</td>
<td>58.74±2.33</td>
<td>-</td>
<td>11.09±4.2</td>
<td>166</td>
<td>n.s</td>
</tr>
<tr>
<td>Tethered swimming</td>
<td>58.74±2.33</td>
<td>131.5±127.8</td>
<td>10.27±3.3</td>
<td>164</td>
<td>n.s</td>
</tr>
</tbody>
</table>

There was a statistical significant correlation between performance time of 100m freestyle and mean force in tethered swimming (r= -0.63, p< 0.05), while no significant correlation was found between performance time in 100m freestyle, mean force in tethered swimming and maximum accumulation of lactic acid.

DISCUSSION
In this study the concentration of lactic acid in elite swimmers in two test of same duration were examined: 100m freestyle swimming and tethered swimming of same duration as in 100m freestyle. The results show that both tests are suitable for the estimation of maximum capacity of anaerobic lactic system. Time performance in 100m and mean strength in tethered swimming are highly correlated.

Lactic acid concentrations were lower in comparison to those reported by Avlonitou (1996) after 100m of all types of swimming (12.0 and 13.1 mmol/L in adult men and 10.5 to 12.6 mmol/L in adult women). Almost the same values of lactate concentration were found by Bonifazi et al. (1993), 10.0 and 11.8 mmol/L and between 9.3 and 10.1 mmol/L respectively. Lower values of lactic acid may be due to the higher competitive level of subjects, as in the present study. High level also means better mechanical performance in propulsion movements. Blood lactate concentrations in tethered swimming were similar to those in freestyle swimming. Only one related study seems to be available, Mitchell & Huston (1993) examined the accumulation of lactic acid in tethered swimming with maximum intensity of approximately 2min duration. Results have shown lactic acid concentration between 9 and 10.4 mmol/L, obviously lower than our values. Furthermore, there are several studies in tethered swimming using protocols with interval efforts and gradually increasing intensity to exhaustion at total duration of approximately 5min (Rinehardt et al., 1991; Ueda & Kurokawa, 1995; DiCarlo et al., 1991). Blood lactate concentrations were between 6 mmol/L and 9 mmol/L, considerably less than those of our subjects. These differences may be due to less participation of anaerobic metabolism during maximum aerobic efforts.

Blood lactate values less than 9.5 mmol/L and 5.5 mmol/L in men were observed in studies that examined the effect of swim bench in anaerobic metabolism of swimmers (Pluto et al., 1988; Konstantaki et al., 1998; Konstantaki & Swaine, 1999). The previous researchers used intermittent protocols with ascending intensity to exhaustion. Blood lactate levels were obviously lower in comparison to this study. These differences occur because of the protocols followed of longer duration.

The significant correlation in the study of Dopsaj (2000) in men between power in tethered swimming and blood lactate concentration confirms the fact that absolute intensity is positively correlated to blood lactate accumulation. A similar tendency was found in the present study though without statistical significance (r=0.32, p=0.06). On the other hand, a maximum muscular effort may be accompanied by high accumulation of lactic acid but without better results in performance.

In conclusion, comparing the effects of the two tests, a similar accumulation of lactic acid was observed in freestyle swimming and in tethered swimming. Thus, blood lactate levels were high in both tests and as a result both are useful in steering training programs for the development of anaerobic lactate capacity. Great relation was found between performance time and strength in tethered swimming.

From the results it is obvious that both tests are suitable for the evaluation of maximum capacity of the anaerobic lactic mechanism, recorded by the maximum accumulation of lactic acid in blood. The tethered swimming test comes behind the 100 meters freestyle test in lactic acid production, probably because it influences the technique of legs in freestyle and as a result the rhythm and the intensity of the effort are reduced (Thanopoulos V, Platanou T, Rozi G, 2009).

CONCLUSION
In conclusion, based on the fact that in the test of tethered swimming, high levels of blood lactate were produced, similar to those in freestyle swimming, it is suggested that tethered swimming can be used for the cultivation of maximum production and tolerance of lactic acid as well as for the estimation of swimming force.

REFERENCES
Cousinsman J. E. (1979). Biokinetics, the ultimate exercise. In R.M. Ousley (Ed) ASCA World Clinic Yearbook 1979 (pp. 29-36). Fort Lauderdale: ASCA.
Dopsaj M. (2000). Reliability of basic mechanic characteristics of pulling force and kinematic indicators of crawl technique measured by the method of tethered swimming with maximum intensity of 10x Physical Culture, 54 (1-4), 35-45.
swimming power and dryland power to sprint freestyle performance: A mul-tiple regression approach. Journal of Swimming Research, 9, 10-14.


Chapter 3. Physiology and Bioenergetics

Blood Lactate Concentration and Clearance in Elite Swimmers During Competition

Vescovi, J.D. 1,2, Falenchuk, O. 1, Wells G.D. 1,2

1Canadian Sport Centre Ontario, Toronto, Canada  
2Faculty of Medicine, University of Toronto, Toronto, Canada  
3School of Kinesiology and Health Science, York University, Toronto, Canada  
4Ontario Institute of Secondary Educ., University of Toronto, Toronto, Canada

Blood lactate [BLa] concentrations after swimming events may be influenced by demographic features and characteristics of the swim race, whereas active recovery (AR) enhances [BLa] removal. Our aims were to examine how sex, age, race distance, and swim stroke influenced [BLa] after competitive swimming events and to develop a model based on AR swim distance to help optimize [BLa] removal. Post-race [BLa] from 100 swimmers competing in the finals at the Canadian Swim Championships were retrospectively analyzed. [BLa] was also assessed repeatedly during AR. Post-race [BLa] was highest after 100 and 200 m events and lowest after 50 and 1500 m races. There was a negligible effect of age on post-race [BLa]. The following model can be used to estimate the change in [BLa] during AR: Δ[BLa] after AR = -3.374 + 1.162 (male=0;female=1) + 0.789 *post-race [BLa]+ 0.003 * AR distance.

Key Words: blood lactate, active recovery, sex differences, swimming

INTRODUCTION

Short duration bouts of high intensity exercise rely largely on non-oxidative energy metabolism, resulting in the accumulation of muscle and blood lactate. Peak blood lactate concentrations ([BLa]) following maximal exercise has a direct relationship with performance in swim events ranging between 100 and 800 m (Benelli et al., 2007; Bonifazi et al., 1993). Evaluation of [BLa] following competitive races also provides evidence of the physiological stress for an individual swimmer in a given event. Thus, the utility of assessing [BLa] for swimmers is important for a variety of training and competitive purposes.

Swimming provides an ideal model for characterizing [BLa] response with events ranging from ~20 s (50 m freestyle) to 15 min (1500 m freestyle). Swimmers commonly compete in multiple events throughout a single day, which requires them to recover from and prepare for several races. Strategies that increase the return rate of post-race [BLa] to resting values are often used by coaches in an effort to optimize subsequent performance. In an effort to expedite blood lactate removal while maximizing energy conservation between swimming events it would be of practical use to know if there is an optimal distance or time to recommend for active recovery (Toubekis et al., 2008).

Research on the effect of sex, age and race characteristics on post-race [BLa] during competitive swim events remains equivocal. Additionally, sport scientists, coaches and swimmers continually search for practical strategies to maximize recovery after an event in preparation for subsequent heat or final races. The aims of this study were to examine how sex, age, race distance, and swim stroke influenced [BLa] after competitive swimming events and to develop a practical model based on recovery swim distance to help optimize blood lactate removal.

METHODS

Post-race [BLa] after the final races in male and female swimmers competing in the 2009 Canadian National Swimming Championships were assessed. The effect of active recovery distance on [BLa] disappearance and a model that could be used by coaches as a practical tool during competitions was also examined. Data from one hundred swimmers (n=50 male and n=50 females) were included in this analysis. Multiple races from the same person were included and thus data from 156 races...
were collected, however because of missing data the final analysis included 149 finals races swam by 98 swimmers. The age of the swimmers ranged between 14 and 29 years. Race results were collected from the host organizing committee and used to determine FINA points.

Blood samples were collected within three to five minutes after completing the race. Samples were obtained from finger stick and analyzed with a Lactate ProTM (Arkray Lt., Japan). Swimmers then proceeded to the recovery pool and performed their own coach–directed active recovery. [BLa] was repeatedly assessed until it was below 2 mmol/L-1. The distance of each active recovery segment as well as the total active recovery distance and the change in [BLa] from post-race to the lowest concentration achieved following the active recovery were recorded.

Several swimmers competed in more than one final race and had data from multiple races included in the analysis, therefore the assumption of independence was violated. To evaluate the relationship between post-race [BLa] and swimmers characteristics (age and sex) and the races (stroke and distance) the Generalized Estimating Equations (GEE) technique was used (Hardin & Hilbe, 2002), which accommodates for a violation of the independence assumption. To evaluate active recovery distance on [BLa] disappearance an exploratory model building approach was used with [BLa] following active recovery as the dependent variable, while sex was entered in the model as a two-level factor. Age, post-race [BLa], and active recovery distance were entered as covariates. The maximal model was developed, then non-significant effects were removed until the most parsimonious model was achieved. Each model was compared with the previous using Quasi Likelihood under Independence Model Criterion (QIC) index to determine whether removal of non-significant parameters improved the fit of the model. Values are expressed as mean ± SD and statistical significance was set at p<0.05.

RESULTS
Mean FINA points for the finals races included in this study was 899±73. Statistically significant predictors from the GEE model are presented in Table 1 and indicated an interaction between sex and swim stroke. Results from the interaction between sex and stroke are presented in Fig. 1. Mean post-race [BLa] for each distance and swim stroke are presented in Fig. 2. Our results indicated age was a significant predictor of post-race [BLa], however the parameter estimates indicated that for a change in age of one year there would be a negligible change in post-race [BLa] of 0.09 mmol/L-1.

A sex difference was observed in post-race [BLa] for freestyle events with male swimmers having higher [BLa] compared to females (13.4±2.6 mmol/L-1 vs. 11.3±3.3 mmol/L-1). The sex difference persisted (13.4±2.6 mmol/L-1 vs. 12.0±2.9 mmol/L-1) even after removal of 1,500 m results, which contained only females and had the lowest [BLa] of 0.09 mmol/L-1.

The exploratory model building analysis used to examine the relationship between active recovery distance and [BLa] removal resulted in the following equation: \[ \Delta[BLa] \text{ after active recovery} = -3.374 + (1.162\times sex) + (0.789\times post-race [BLa]) + (0.003\times active recovery distance) \]. This equation was then used with the 95% confidence intervals of post-race [BLa] for each race distance to construct active recovery distances (see Table 2).

DISCUSSION
The highest [BLa] were reported following 100 and 200 m events, regardless of the swim stroke, indicating the high anaerobic demands for these race distances. In contrast to previously published reports (Avlonitou, 1996; Benelli et al., 2007), no independent effect of sex and a negligible effect of age as determinants of post-race [BLa] were observed. The current group of athletes were high-level swimmers, as evidenced by the high mean FINA points. It has previously been reported that peak [BLa] occur when competing in main competitions (Bonifazi et al., 2000), therefore our findings likely reflect those experienced by elite swimmers during major competitions.

An inverted U-shaped [BLa] profile across the swim distances were
found. This pattern has previously been described (Avlonitou, 1996; Bonifazi et al., 1993) and reflects the energetic demands for each distance. Because of the short duration of 50 m races (1-20 s) the ATP-PC system is able to supply a substantial proportion of the energy needed for these events, thus blood lactate concentration was lower in comparison to 100-800 m events. Within the 50 m events, post-race [BLa] was lowest for breaststroke and highest for butterfly. Our findings that the highest post-race [BLa] were observed following the 100 and 200 m races was not surprising as other researchers have reported similar outcomes in elite (Bonifazi et al., 1993; Bonifazi et al., 2000) and college swimmers (Sawka et al., 1979). Thus, even though it is estimated that a large proportion of the energy supplied for events of this duration comes from oxidative metabolism substantial blood lactate accumulation occurs during these events.

Table 2. Suggested active recovery distances

<table>
<thead>
<tr>
<th>Event</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freestyle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1000-1200</td>
<td>600-800</td>
</tr>
<tr>
<td>100</td>
<td>1300-1500</td>
<td>800-1000</td>
</tr>
<tr>
<td>200</td>
<td>1300-1500</td>
<td>800-1000</td>
</tr>
<tr>
<td>400</td>
<td>1300-1500</td>
<td>800-1000</td>
</tr>
<tr>
<td>800</td>
<td>1000-1200</td>
<td>600-800</td>
</tr>
<tr>
<td>1500</td>
<td>800-1000</td>
<td>600-800</td>
</tr>
<tr>
<td>Backstroke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1000-1200</td>
<td>600-800</td>
</tr>
<tr>
<td>100</td>
<td>1300-1500</td>
<td>1000-1200</td>
</tr>
<tr>
<td>200</td>
<td>1300-1500</td>
<td>1000-1200</td>
</tr>
<tr>
<td>Breaststroke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>800-1000</td>
<td>500-800</td>
</tr>
<tr>
<td>100</td>
<td>1200-1400</td>
<td>800-1000</td>
</tr>
<tr>
<td>200</td>
<td>1200-1400</td>
<td>800-1000</td>
</tr>
<tr>
<td>Butterfly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1200-1400</td>
<td>700-900</td>
</tr>
<tr>
<td>100</td>
<td>1200-1400</td>
<td>800-1000</td>
</tr>
<tr>
<td>200</td>
<td>1200-1400</td>
<td>800-1000</td>
</tr>
<tr>
<td>Individual Med.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>1200-1400</td>
<td>800-1000</td>
</tr>
<tr>
<td>400</td>
<td>1200-1400</td>
<td>800-1000</td>
</tr>
</tbody>
</table>

Sex differences in post-race [BLa] have been reported for top level (Bonifazi et al., 1993) and age group (Avlonitou, 1996) swimmers, but not all events display a substantial disparity between men and women (Avlonitou, 1996; Bonifazi et al., 1993). The post-race [BLa] distribution curve is shifted to the right for males compared to females (Bonifazi et al., 1993) and [BLa] tends to be about 1 mmol•L⁻¹ higher in most events for men (Avlonitou, 1996). A sex difference existed in post-race [BLa] only following freestyle events with male swimmers achieving a greater [BLa] compared to women. Only female swimmers competed in, and were subsequently evaluated after, the 150 m freestyle event, which had the lowest mean post-race [BLa]. However the sex difference persisted even when the outcomes from the 1500 m freestyle event were removed from the analysis.

Previous research has reported post-race [BLa] tend to be greater following IM events, whereas breaststroke tends to result in lower [BLa] regardless of age or sex (Avlonitou, 1996; Bonifazi et al., 1993; Sawka et al., 1979). Interestingly, our male swimmers had similar post-race [BLa] across all swim strokes. In contrast, the female swimmers displayed a 7-21% greater post-race [BLa] for IM events compared to freestyle, breaststroke and butterfly races. The lack of difference between strokes for males is unclear, however the observed relative difference between IM and other strokes for females is similar, albeit on the lower end, to others who demonstrated a 25-60% greater post-race [BLa] for IM compared to other strokes of equal distance in age group (Avlonitou, 1996) and college (Sawka et al., 1979) swimmers.

Swimmers in the current study completed an active recovery according to their individual coach’s assigned protocol. While not experimentally optimal, it reflects the reality of swim meets, and thus the recovery distances recommended in this paper may be more widely implemented than if the protocols were rigidly controlled. As an example of the utility of our model, if a female swimmer competed in the 200 m freestyle final and had a post-race [BLa] of 12.5 mmol•L⁻¹, an active recovery of 600 m or 1200 m would be expected to reduce [BLa] by 9.5 mmol•L⁻¹ and 11.3 mmol•L⁻¹, respectively, which would result in a post active recovery [BLa] of 3.0 mmol•L⁻¹ or 1.3 mmol•L⁻¹. Taken together with the findings of Greenwood et al. (Greenwood et al., 2008) and subsequent swimming performance, coaches can now specify the distance and intensity of the active recovery to maximize blood lactate clearance.

CONCLUSION
The results of a comprehensive analysis of blood lactate levels across a range of swimming events are reported. Furthermore, an estimate of lactate clearance by gender and event which is a practical tool for coaches is presented.

REFERENCES

ACKNOWLEDGEMENTS
Funding provided by Canadian Sport Centre Ontario. Thanks to R. Ruëf, E. Fernandez, C. Dalcin, T. Zochowski, S Farra.
Determination and Validity of Critical Velocity in Front Crawl, Arm Stroke and Leg Kick as an Index of Endurance Performance in Competitive Swimmers

Wakayoshi, K. 1, Shiraki, T. 1, Ogita, F. 2, Kitajima, M. 3

1Biwako Seiki Sport College, Japan
2National institute of Fitness and Sports, Japan
3Hyogo High School, Japan

The purposes of this study were to determine critical velocity (Vcri) in swim, pull and kick tests, and also to examine whether Vcri correspond to the exercise intensity at maximal lactate steady state (MLSS) for each stroke. Fourteen male trained college swimmers volunteered for this study. A regression analysis of swimming distance on time calculated for each swimmer showed linear relationships (r²=0.998, p<0.010) for all strokes. In MLSS test, all subjects could maintain the Vcri for 20 min in the respective strokes. In addition, no significant differences were found in BL measured among swim, pull and kick. These data suggest that Vcri can be determined by the relationship between distance and time, not only in swimming but also in pull and kick, and Vcri obtained by each stroke would correspond approximately to the exercise intensity at MLSS.

Key words: critical velocity, swim, pull, kick and maximal lactate steady state

INTRODUCTION

The concept of critical power (Monod and Scherrer 1965, Moritani et al. 1981) is applied to the field of competitive swimming as critical swimming velocity (Vcri) in the swimming flume (Wakayoshi et al. 1992a). Vcri, defined as the swimming velocity which could be theoretically maintained without exhaustion, was expressed as the slope of regression line between swimming distance (D) at each velocity and its sustained time (T). Furthermore, Vcri is determined in the normal swimming pool (Wakayoshi et al. 1992b) as well as the swimming flume, as in the previous study of Wakayoshi et al. (1992a), and suggested that Vcri in the normal pool could be adopted as a simple and valuable index for swimming endurance performance without requiring blood sampling or the use of highly expensive equipment (Wakayoshi et al. 1992b). In addition, Wakayoshi et al. (1993) have suggested that Vcri, which can be calculated by maximal effort swimming of two different distances (200m and 400m), may correspond to the exercise intensity at maximal lactate steady state (MLSS) promoted by Scheen et al. (1981) and Stegmann and Kindermann (1982).

During whole stroke swimming, the propulsion is generated by the action of both arms and legs. Therefore, daily swimming training consists not only of whole stroke but also of pull or kick only, because it has been considered that to strengthen metabolic capacity in local muscles would improve more effectively whole stroke performance. Therefore, if Vcri of pull (Vcri-p) and kick (Vcri-k) as well as whole stroke (Vcri-s) are determined, those would provide an important implication for setting an appropriate intensity for endurance training. However, to our knowledge, Vcri-p and Vcri-k has not been determined, yet, and thus the relationships between the Vcri for pull and for kick and the MLSS for each stroke has not been clarified, either.

Therefore, the purposes of this study were to determine Vcri-p and Vcri-k as well as Vcri-s, and also to examine whether Vcri-s, Vcri-p and Vcri-k correspond to the exercise intensity at MLSS for each stroke.

METHODS

The subjects who volunteered for this study were 14 well-trained college male swimmers (19-21 years). The subjects were informed about the design of the study and signed a statement of informed consent. All swimming tests were performed in a swimming flume.

For the determination of Vcri, the subjects swam at five constant water flow velocities, which ranged from 1.2m/s to 1.7m/s for Vcri-s and Vcri-p, and from 0.8m/s to 1.3m/s for Vcri-k. The end point was marked by a line placed rectangularly to the water flow 1 m behind the point where the subject began to swim. Figure 1 illustrates the determination (subject 1) of Vcri.

Figure 1 illustrates relationship between predetermined velocity and time for which that velocity could be maintained (T) and between swimming distance (D) and T plotted from the data of subject 1.

For each test, the swimming velocity (V) of the swimming flume multiplied by T until the subject could no longer maintain his velocity equaled D.

D = V x T  

In the lower part of Fig.1, D obtained from five different swimming velocities was plotted as a function of T. Those points were accurately situated on a line defining the relationship between D and T.

The equation of the regression line could be expressed as follows:

D = a x T + b  

(1)

D can be substituted by V x T from equation (1), giving:

V x T = a x T + b  

(2)

V = a + b/T  

(3)

Theoretically, if V was set at a level which could be performed indefinitely, b/T would approach zero and V would approach a. Therefore, V could be expressed as the slope of the regression line: Vcri=a

MLSS test was conducted to determine whether Vcri-s, Vcri-p and Vcri-k corresponded to the exercise intensity at MLSS. Figure 2 illustrates the experimental design of MLSS test. The swimmers were asked to swim using whole stroke, pull and kick for 20 min (5 min x 4 stages) at the velocity corresponding to Vcri-s, Vcri-p and Vcri-k, and the 20 min-swim was interrupted by three short rest periods for 30 to 60 s for blood sampling. Blood lactate concentration (BL) was determined before, during the three rest periods, immediately after, and 3 and 5 min after each trial.

Data are presented as mean and SD. Statistical evaluation of the data in BL was accomplished by one-way repeated measures analysis of variance. Statistical significance was set at p<0.05.

Figure 2. The experimental design of maximal steady state test for examining the relationship between 20 min (5 min x 4 stages) swim for three strokes and change of blood lactate concentration.
RESULTS

Table 1 shows the physical characteristics, Vcri and correlation coefficient in swim, pull and kick for each subject.

The experimental plots used to determine Vcri of subject 1 are shown in Fig. 1 as an example. The relations between distance (D) and time (T) in swim, pull and kick were expressed in the general form, D = a + b x T, with r2 value (goodness of fit) showing higher than 0.998 (p<0.001) in all subjects. These results of Vcri in all strokes indicated extremely good linearity. Vcri-s, Vcri-p and Vcri-k ranged from 1.19 to 2.04 m/s with a mean of 1.30 m/s (SD=0.08), from 1.15 to 2.17 m/s with a mean of 1.26 m/s (SD=0.07) and from 0.81 to 1.04 m/s with a mean of 0.92 m/s (SD=0.07), respectively.

Table 1. Physical characteristics, Vcri and correlation coefficient for each subject

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Vcri-s (m/s)</th>
<th>Vcri-p (m/s)</th>
<th>Vcri-k (m/s)</th>
<th>r</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>185.2</td>
<td>78.8</td>
<td>0.999</td>
<td>1.29</td>
<td>0.999</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>175.2</td>
<td>63.7</td>
<td>0.999</td>
<td>1.30</td>
<td>0.999</td>
<td>0.93</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>19</td>
<td>172.4</td>
<td>68.0</td>
<td>0.999</td>
<td>1.15</td>
<td>0.999</td>
<td>0.03</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>174.7</td>
<td>67.9</td>
<td>0.999</td>
<td>1.32</td>
<td>0.999</td>
<td>0.81</td>
<td>0.999</td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>173.6</td>
<td>66.5</td>
<td>0.999</td>
<td>1.29</td>
<td>0.999</td>
<td>0.91</td>
<td>0.999</td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>166.7</td>
<td>58.2</td>
<td>0.999</td>
<td>1.30</td>
<td>0.999</td>
<td>1.02</td>
<td>1.000</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>187.5</td>
<td>78.5</td>
<td>0.999</td>
<td>1.23</td>
<td>0.999</td>
<td>0.83</td>
<td>0.999</td>
</tr>
<tr>
<td>8</td>
<td>21</td>
<td>172.5</td>
<td>80.0</td>
<td>0.999</td>
<td>1.29</td>
<td>0.999</td>
<td>0.95</td>
<td>0.999</td>
</tr>
<tr>
<td>9</td>
<td>21</td>
<td>178.8</td>
<td>73.7</td>
<td>0.999</td>
<td>1.33</td>
<td>0.999</td>
<td>0.01</td>
<td>0.999</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>180.7</td>
<td>74.5</td>
<td>1.000</td>
<td>1.36</td>
<td>0.999</td>
<td>0.98</td>
<td>0.999</td>
</tr>
<tr>
<td>11</td>
<td>20</td>
<td>180.0</td>
<td>71.2</td>
<td>0.999</td>
<td>1.47</td>
<td>1.000</td>
<td>0.86</td>
<td>1.000</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>171.7</td>
<td>61.6</td>
<td>0.999</td>
<td>1.36</td>
<td>0.999</td>
<td>1.04</td>
<td>1.000</td>
</tr>
<tr>
<td>13</td>
<td>19</td>
<td>177.5</td>
<td>60.5</td>
<td>0.999</td>
<td>1.41</td>
<td>0.999</td>
<td>0.91</td>
<td>1.000</td>
</tr>
<tr>
<td>14</td>
<td>19</td>
<td>170.0</td>
<td>62.8</td>
<td>0.999</td>
<td>1.44</td>
<td>0.999</td>
<td>0.97</td>
<td>0.999</td>
</tr>
</tbody>
</table>

Table 1 shows the physical characteristics, Vcri and correlation coefficient for each subject.

Interestingly, Vcri observed in this experiment was almost equal or rather higher when compared to Vcri-s. This might be explained by the use of pull-buoys while pulling thus enabling more efficient stroking in Vcri-p as compared to Vcri-s.

Since Vcri is a certain index for endurance capacity, this result implies that the propulsion for whole stroke is generated mostly by the arm action as the swimming distance becomes longer. This conjecture is in line with the results of BL in MLSS tests, that is, the values of BL in pull were almost equal to those in swim (4.5 mmol/L), but those in kick (6.7 mmol/L) tended to be higher, suggesting that the metabolic demand for leg muscles during swim should be much lower than that during leg kick. On the other hand, maximal speed in swim is generally higher than that in pull. Therefore, leg kick should contribute the generation of the total propulsion of the swim, especially in sprint event. Actually, in the short lasting exhaustive swimming (<1min), the metabolic demand or relative exercise intensity (%VO2max) for kick is much higher than those for pull and swim (Ogita et al. 2003), indicating that leg muscles involved in kick can generate higher metabolic power in a limited short duration. Based on these data, when Vcri-k is improved by the training, then, it is very interesting to examine whether such improvement of endurance performance for kick can contribute to improve the performance for swim. Further experiments are needed to clarify the question.

CONCLUSION

It was found that Vcri could be determined by the relationship between distance and time, not only in swim but also in pull and kick, and Vcri obtained by each stroke would correspond approximately to the exercise intensity at MLSS. Thus, these results suggest that Vcri not only in swim but also in pull and kick can be used to assess the physical performance without the need for either blood sampling or expensive equipment and that Vcri can be adopted as an effective index for swimming coaches and swimmers.

REFERENCES


Figure 3. The relationship between blood lactate concentration and the number of 5 min 4 stages in swim, pull and kick in the swimming flume.

Figure 3 illustrates the changes in blood lactate concentration as a function of stages for each stroke of MLSS test. All subjects could maintain the Vcri for 20 min in the respective strokes. Mean values of BL measured after 4 stages were approximately the same in each test and there was no significant difference among the values of BL for each stage in swim, pull and kick.

DISCUSSION

The primary goal of this investigation was to determine Vcri, i.e. the velocity that swimmers could maintain over a very long period of time without exhaustion, in pull and kick as well as swim, and to examine whether Vcri in pull and kick also correspond to the exercise intensity at MLSS for each stroke.

In this experiment, each swimmer swam at 5 different velocities for each stroke in the flume, in order to calculate Vcri. A strong correlation was found between D and T (r2=0.998) in all strokes for every subject, so that the relationship D = a x T + b, was remarkably linear. These findings mean that the concept of Vcri is applicable to pull and kick as well as swim, and the obtained Vcri-p and Vcri-k could be also useful assessment for endurance capacity in arm stroke and leg kick, which can obtain without requiring blood sampling or the use of highly expensive equipment.

Wakayoshi et al. (1992a, 1992b, 1993) revealed that Vcri observed in swimming significantly correlated with several indices for endurance capacity, such as oxygen consumption at anaerobic threshold, the swimming velocity at the onset of blood lactate accumulation and the mean velocity of 400 m freestyle. Moreover, they have suggested that Vcri, which is calculated by the times of 200m and 400m in the normal pool, would correspond approximately to the exercise intensity at MLSS. Supporting those previous findings, all subjects in this experiment could maintain the Vcri for 20 min in all strokes, and the values of BL showed almost a steady state while the MLSS test, that is, there was no significant difference among the mean values of BL after each stage in each stroke. Furthermore, the values of BL at each stage were not significantly different among strokes. The results of this study suggest that the Vcri determined by pull and kick as well as swim correspond approximately to the intensity of MLSS and that those measurements could provide useful guideline for setting an appropriate intensity for endurance training for arm pull and leg kick.

Interestingly, Vcri-p observed in this experiment was almost equal or rather higher when compared to Vcri-s. This might be explained by the use of pull-buoys while pulling thus enabling more efficient stroking in Vcri-p as compared to Vcri-s.
Biomechanics and Medicine in Swimming IX, eds., Saint-Etienne, 361-366.


Differences In Methods Determining The Anaerobic Threshold Of Triathletes In The Water

Zoretić, D. 1, Wertheimer, V. 2, Leko, G. 1

1Faculty of Kinesiology, University of Zagreb
2Croatian Academic Swimming Club „MLADOST“

The goal of this research is to examine the differences between three various methods for determining the anaerobic threshold, i.e. differences in heart frequencies with regard to the anaerobic threshold (FSanp-1, FSanp-2, FSanp-3). 13 Croatian triathletes swam a progressive interval test of 7 x 200 meters. The evaluation of functional ability was measured by: maximum heart frequency, maximum speed, maximum lactate, anaerobic threshold FS and anaerobic threshold lactate, for three different methods. Results showed high correlation (r=0.91) between FSanp-1 (intersection method) and FSanp-3 (D-max method), while the t-test for dependant samples showed that no statistically significant differences exist, the same demonstrating that those two different measures for determining the anaerobic threshold are reliable in evaluating the anaerobic threshold in swimmers.

Key words: „Intersection” method, 4 mmol/l method and D-max method, swimming

INTRODUCTION

The main problem in testing swimmers and triathletes is the implementation of a protocol in the water where ventilation parameters can't be monitored requiring tests that include monitoring metabolic parameters. Testing these athletes outside the water does not ensure adequate and reliable results due to the specificity of water training: decreased body temperature, higher pressure volume of the heart, lower maximum heart frequency and lower energy consumption (Maglischo, 2003). Various methods exist for determining the anaerobic threshold based on the speed-lactate curve. One of the methods used for establishing the anaerobic threshold is the fixed lactate model proposed by Kindermann (1979), and upgraded by Sjodin and Jacobs (1981) by introducing the OBLA (Onset of blood lactate accumulation). Based on that initial model, the anaerobic threshold was fixed at 4mmol/l, while the aerobic threshold precedes it at 2mmol/l. A special interpretation of the lactate threshold arose after the existence of individual differences in the blood lactate concentration, at the lactate anaerobic threshold, was confirmed. The original method by Stegmann and Associates (1981), defining the individual anaerobic threshold (IAT) as the exercise intensity at which the speed-lactate curve changes its shape from a curve to a straight linear (Maglischo, 2003). This method is also known as the intersection method. Cheng and Kuipers have, in 1992, described a new procedure, they call the D-max method, for determining the anaerobic threshold, using a starting and terminating curve point. The line is set by the basic course of variable change. Thereafter, a point is set on the curve that is the farthest from the line. Said point represents a change in trend and the authors believe it corresponds with the anaerobic threshold (Maglischo, 2003).

The purpose of this paper is to determine whether statistically significant differences exist between 3 various methods of anaerobic threshold determination (the „Intersection” method, the 4 mmol/l method and the D-max method), i.e. differences in heart frequencies at the anaerobic threshold level (FSanp-1, FSanp-2, FSanp-3) during the swimmers’ progressive test. The importance of the anaerobic threshold determinant lies in the subsequent simplicity in establishing training zones and achieving planned training goals.

METHODS

The subjects were a group of 13 Croatian triathletes of a recreational and national level, of which there were 10 male and 3 female triathletes, at an
average age of 27.1 ± 5.9 years. When selecting subjects, the prerequisite was to have at least one year of training and competitive experience in triathlon, as well as being of satisfactory health.

<table>
<thead>
<tr>
<th>Table 1: Descriptive parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS±SD (min-max)</td>
</tr>
<tr>
<td>AGE (yrs)</td>
</tr>
<tr>
<td>body height (cm)</td>
</tr>
<tr>
<td>body mass (kg)</td>
</tr>
<tr>
<td>%BF (%)</td>
</tr>
</tbody>
</table>

AGE – years, body height (cm), body mass (kg), %BF - Subcutaneous Body Fat

Sample of Variables

a) A set of variables for evaluating anthropometric characteristics

Measurement of examinees’ morphological characteristics was carried out in accordance with the guidelines of the International Biological Program (IBP, Misioj-Duraković 2008). Basic morphological variables were measured in order to determine the examinees’ morphological status. With the help of anthropometric instruments and a medical scale, the variables of body mass and body height were measured, while the subcutaneous body fat was established based on the method of biological impedance, using the Tanita BC-418 (TANITA, USA) scale. Eight electrodes (4 for the arms, 4 for the feet) are used to send a weak electric signal through the entire body. In those locations where the resistance, i.e. impedance is higher, the signal needs more time to travel, indicating a higher content of subcutaneous body fat.

b) Set of variables for evaluating functional abilities

1) FSαmax (BPM) - Maximum Heart Frequency, 2) Vmax (m/s) Maximum Speed, 3) LACmax (mmol/l) - Maximum Lactates, 4) FSαnip-1 (BPM) - Anaerobic Threshold Heart Frequency ( „intersection method”), 5) FSαnip-2 (BPM) - Anaerobic Threshold Heart Frequency ( „D-max method”), 6) FSαnip-3 (BPM) - Anaerobic Threshold Heart Frequency ( „D-max method”), 7) LACαnip-1 (mmol/l) - Anaerobic Threshold Lactates ( „intersection method”), 8) LACαnip-2 (mmol/l) - Anaerobic Threshold Lactates ( „4 mmol/l”), 9) LACαnip-3 (mmol/l) - Anaerobic Threshold Lactates ( „D-max method”).

Specified parameters were determined based on three various methods.

Prior to testing, the examinees were acquainted with the testing protocol which, with regard to the swimming test, consists of seven (7) 200 meter sections with a 5 minute active rest regime in a small swimming pool. Each section is covered by applying a faster swimming pace, up to the maximum and at an even pace. How fast each examinee swam through a certain section was determined based on the best 200 meter result, the same being tested a few days prior to the swimming test. The obtained result was increased by 5 seconds in order to get the fastest seventh section. Every previous section is also increased by 5 seconds in order to get the swimming pace for each set section which the swimmer must comply with. An example of calculating swimming speed for each of the set sections is shown in Table 6. Specified swimming pace was dictated by an assistant by the pool, using a whistle every 25 or 50 m. During testing, the examinees wore a pulse meter (Polar RS 400, Finland) the whole time, and at each section’s end, the concentration of lactates in the blood was measured with a Lactate Scout device (SensLab, Germany). Immediately prior to starting a new section (about 15-30 seconds prior), the examinee would enter the pool and prepare for start. In order for the transmitter of the pulse meter to be attached to the examinees’ chests, all the examinees wore swimsuits.

Results obtained by measurement procedures were processed by a data analysis software system Statistic version 8.0. In order to determine statistically significant differences between various methods used to establish the anaerobic threshold of the subjects, the t-test was used for dependent samples.

RESULTS

Assessed means, standard deviation, minimal and maximal results, skewness and kurtosis for certain variables is presented in Table 2. Test for dependant variables showed that there is no statistical significant difference between FSαnip-1 and FSαnip-3 (Table 3).

Table 2: Descriptive Values of Certain Variables

<table>
<thead>
<tr>
<th>Valid N</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Std.Dev.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSmax</td>
<td>13</td>
<td>180.15</td>
<td>170</td>
<td>192</td>
<td>7.50</td>
<td>0.065</td>
</tr>
<tr>
<td>LACmax</td>
<td>13</td>
<td>11.31</td>
<td>6.6</td>
<td>19.2</td>
<td>2.99</td>
<td>1.236</td>
</tr>
<tr>
<td>Vmax</td>
<td>13</td>
<td>1.13</td>
<td>0.96</td>
<td>1.36</td>
<td>0.11</td>
<td>0.415</td>
</tr>
<tr>
<td>LACαnip-1</td>
<td>13</td>
<td>4.63</td>
<td>3.3</td>
<td>6</td>
<td>0.80</td>
<td>0.015</td>
</tr>
<tr>
<td>LACαnip-2</td>
<td>13</td>
<td>4.00</td>
<td>4</td>
<td>4</td>
<td>0.00</td>
<td>--</td>
</tr>
<tr>
<td>LACαnip-3</td>
<td>13</td>
<td>4.98</td>
<td>3.3</td>
<td>7.3</td>
<td>1.15</td>
<td>0.521</td>
</tr>
</tbody>
</table>

High correlation values (Table 3) are indicative of a link between FSαnip-1 and FSαnip-2 which shows that the purpose of measurement is the same and that predicting results by using the D-max method based on the „intersection method” is 82% successful, while predicting results through the D-max method based on the 4 mmol/l method is much less successful, i.e. 54%.

DISCUSSION

Large differences between maximum values of lactate in the blood suggest various degrees in which the body is able to react to acidosis. Naturally, those values are conditioned by training as well, and if looking at each examinee separately, it is noticeable that examinees that are more trained are able to increase speed one section after another, regardless of the rise of blood lactate and the decrease of pH value. Said values of maximum blood lactateise a generally accepted aerobic capacity parameter and the buffering ability of the muscles.

Values of the maximum heart frequency in this test are the highest value achieved in a test, but the maximum. In order to achieve maximum heart frequency values, the test must be shorter, without intervals and more intense.

It would be logical that there are no statistically significant differences between all these measures because the object measured is the same. Table 3 shows a high correlation (r=0.91) between FSαnip-1 („intersection method”) and FSαnip-3 (D-max method), while the t-test for dependant samples showed (Table 3) that no statistically significant difference exists, the same demonstrating that those two different measures for determining the anaerobic threshold are reliable in evaluating the anaerobic threshold in swimmers.
Furthermore, Table 3 shows that a statistically significant difference exists between FS\textsubscript{anp}-2 (4 mmol/l method) with FS\textsubscript{anp}-1 and FS\textsubscript{anp}-3, thereby proving it to be a deviating measure, meaning that it does not target the same qualities.

According to Stegmann and associates, 1981, it is impossible to fix the threshold at 4 mmol/l for everyone (FS\textsubscript{anp}-2), so therefore it is necessary to determine the so called IAT – individual anaerobic threshold (FS\textsubscript{anp}-1). In their research, Stegman and Kindermann have shown that the individual anaerobic threshold is different in relation to the threshold obtained by a fixed concentration of lactates at 4 mmol/l. The „Interaction“ method, i.e. the individual anaerobic threshold represents a reliable way of evaluating the lactate anaerobic threshold (Urhausen, 1993), and if carried out carefully it provides overall consistent results with athletes or within the clinical population (Svedahl and MacIntosh, 2003). Establishing the anaerobic threshold at 4 mmol/l has its advantages, considering the objectivity of determination, but also a great disadvantage due to ignoring individual differences and individual lactate kinetics. That is, not all examinees show a significant increase of lactate at 4 mmol/l, but this range is much wider, spanning from 3-6 mmol/l, up to as much as 9 mmol/l (MacIntosh and Assoc., 2002.; Billat and Assoc.2003).

A graphical overview of FS\textsubscript{anp} values shows that the lowest values of FS\textsubscript{anp-1}, i.e. heart frequency were determined by the 4 mmol/l method. A higher similarity of incidence and higher values between FS\textsubscript{anp-1} and FS\textsubscript{anp-3} are also clearly visible.

![Graph depicting FS\textsubscript{anp} values comparison](image)

Figure 1: Comparison of FS\textsubscript{anp} Percentage Values from FS\textsubscript{max} Obtained by Three Different Methods

It is important to know that, on average, untrained persons will exceed the threshold at only 30-60% of maximum load, while top athletes in aerobic sports do the same at 85-95% of maximum load (Janssen, 2001). The percentage values of FS\textsubscript{anp} incidence are very high and should not be taken literally, since unfortunately maximum values of heart frequency have not been obtained. According to Maglischo, 2003, the maximum heart frequency value for swimmers must be tested in the water, while an additional prerequisite of obtaining maximum heart frequency values is reading the values during or immediately after maximum performance lasting between one and two minutes.

**CONCLUSION**

Today, there are several definitions of the term anaerobic threshold. The anaerobic threshold is considered to be the intensity at which the oxygen supply system activates the mechanism of anaerobic glycolysis in a more significant way, and at which the accumulation of lactic acid is equal to its breakdown. The method most often used in practice is the ventilation method, but its application in water is almost impossible, whereas the second mostly used method is the heart frequency deflection point that can be determined on a heart frequency curve obtained from a continuous test. For that reason, testing in the water is significantly more difficult, thereby making the anaerobic threshold determination more difficult as well. In the course of this research, three methods were used to determine the anaerobic threshold: 1) the „intersection“ method (IAT), 2) the 4 mmol/l method, and the 3) D-max method. Both the „Intersection“ method and the D-max method have been shown to be a reliable manner of evaluating the anaerobic threshold, and if applied carefully they provide generally consistent results in swimmers.

**REFERENCES**


Mišigoj-Duraković M. Kinanthropologija. Biološki aspekti tjelesnog vježbanja (Kinanthropology. Biological Aspects of Physical Exercise). Faculty of Kinesiology, University of Zagreb, 2008; 130-150


Chapter 4. Training and Performance
Physical Responses and Performance Characteristics of 200m Continuous Swimming and 4x50m "Broken Swimming" with Different Rest Intervals

Beidasri, N., Botonis, P. and Platanou, T.
Faculty of Physical Education and Sport Science, University of Athens, Greece

The purpose of the present study was to investigate the physiological responses and performance characteristics of "broken" swimming (4x50m) with different rest intervals (5, 10 and 20s) compared with those of continuous swimming (200m) during maximum intensity free-style swimming. Twelve voluntary swimmers of competitive level (aged: 14-17 years) were tested. Significant differences were observed in performance time and heart rate between continuous and "broken" swimming with resting interval of 20s (F=4.27, P<0.009 and F=3.31, P=0.03, respectively). However, no differences were found in blood lactate and oxygen consumption. In conclusion, it seems that even if the physiological responses were similar between conditions, the performance characteristics were higher in the condition of broken swimming with 20s resting interval.

Key words: VO\textsubscript{2}, Lactate, Heart rate, performance, speed, number of strokes

INTRODUCTION

In swimming training, various methods have been employed for the improvement of swimming endurance and speed. "Broken" swimming is a mode of interval and repeated training for maintaining high rate and speed of swimming of a distance with maximum intensity ("broken" swim, Maglischo 1993). According to this method, the total swimming distance is divided into smaller distances with short rest intervals during which athletes swim to their limits, maintaining the highest speed possible. The rest intervals between swims could be either long (20 s) or short (5 s), during which swimmers maintain the same speed and speed throughout the total distance. The total time is estimated by subtracting the rest interval time from the total time of the total distance. Additionally, the above method is mainly used as a test of performance in a given distance before competition.

The physiological responses and the performance characteristics are very important for a coach who needs to analyze the training data and to gain feedback for the results of a method as a way for achieving the competition goals. It is known that heart rate is an exercise intensity index as are blood lactate and maximal oxygen consumption. In particular, during high intensity exercise, the heart rate and heart muscle contractility are increased to deliver more blood to exercising muscles. Heart rate is considered as a main training guide by many researchers (Chen et al. 2002, Niewiadomski et al. 2007).

Moreover, lactic acid is produced during exercise and it is well established that during high intensity exercise, the lactate production is increased. During the first stages of exercise, O\textsubscript{2} deficit is evident, and as a result lactic acid is increased for energy production. The blood lactate concentration is another main index of exercise intensity (Billat 1996). Oxygen consumption is also an index of exercise intensity and can be used to evaluate the contribution of aerobic energy during exercise (Fernandez et al., 2003). It shows the cardiovascular and muscle ability of the body to consume O\textsubscript{2} per unit time. The increment of oxygen consumption is linear and is related to the exercise intensity.

However it is not known, if the physiological responses and performance characteristics are similar between interval and continuous training. The purpose of this study was to investigate: 1) the physiological responses of "broken" swimming (4x50m) with different resting intervals compared with those of continuous swimming (200m) during maximum intensity free-style swimming and 2) which resting interval in "broken" swimming, contributes to the development of higher swimming speed with similar physiological demands compared to those of continuous swimming. The hypotheses in this study are that 1) the maximum lactate concentration and oxygen consumption would be similar at the end of the 200m swimming, regardless of the resting interval between the 50m swims. 2) The heart rate during the 200m swimming would be expected to be different because the intensity of exercise would be dependent on the previous resting interval and 3) the performance related characteristics in "broken" swimming would be expected to be different. It is expected that a long resting interval would contribute to a higher swimming performance.

METHODS

Twelve swimmers (aged: 14-17 years) with at least five years of training age were tested in 4 exercise conditions: in 200m and in 4x50m of free-style swimming with 5, 10 and 20 s rest intervals between swims. In all sets, A) Physiological parameters: 1. oxygen consumption (VO\textsubscript{2max test (400m free style swimming) was conducted in order to estimate the oxygen consumption as a percentage (%) of VO\textsubscript{2max by backward extrapolation. The reliability and validity of backward extrapolation has been previously tested (Leger et al. 1980, Montpetit 1981). According to that method, the air is collected at the end of exercise in 4 different times of 20 s and then a linear backward regression curve is conducted. Afterwards, each participant swam 200m and on a separate day 4x50m free style swimming of maximum intensity with 5, 10 and 20 s resting interval between swims in a random order. At the end of each condition the O\textsubscript{2} deficit was calculated by measuring the exhaled air for 2-min during recovery. Immediately after the swimming test, the participants expired directly into a respiratory valve that was connected to the metabolic card. During each test, heart rate was recorded every 5 seconds. The rate of perceived exertion which is considered as a fatigue index was measured at the end of the test by the Borg scale. Blood samples for lactate concentration measurement were taken at 3, 5 and 7 minutes of recovery. Moreover, the performance time was recorded for each 50m swim and for the total distance by a hand chronometer.

All results are expressed as mean values (±SD). One way ANOVA for dependent samples was used to define the overall differences in each variable. Furthermore, one way ANOVA for dependent samples with repeated measurements was used to define differences in each variable between 50m swims. A Tukey test was employed to assign specific differences in the analysis of variance. Statistical significance was set at P<0.05.

RESULTS

The mean VO\textsubscript{2}max for all participants was 2.83±0.69 l·min\textsuperscript{-1}. Significant differences were observed for the time of performance, heart rate and mean speed between conditions (F=4.27, P=0.009; F=3.31, P=0.03 and F=4.15, p=0.01, respectively). Lactate concentration and oxygen uptake were similar between conditions (p=0.98 and p=0.39). Significant differences between continuous and "broken" swimming with 20s. rest interval were observed in performance (2:29.33±9.27 vs 2:17.12±7.78), in mean speed (1.33±0.08 m·s\textsuperscript{-1} vs 1.45±0.09 m·s\textsuperscript{-1}) and in heart rate (184.23±5.26 vs 195.38±11.87, Table 1).
Table 1. Physiological and performance variables in 200m and 4x50m of free style swimming with 5, 10 and 20s rest intervals for all participants (n=13).

<table>
<thead>
<tr>
<th>Conditions</th>
<th>1st 50m</th>
<th>2nd 50m</th>
<th>3rd 50m</th>
<th>4th 50m</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>200m</td>
<td>46.51±4.99</td>
<td>46.38±4.92</td>
<td>46.00±5.21</td>
<td>46.00±5.14</td>
<td>46.20±4.98</td>
</tr>
<tr>
<td>4x50 m (5 s)</td>
<td>48.07±6.07</td>
<td>48.00±5.53</td>
<td>49.46±5.93</td>
<td>49.46±5.51</td>
<td>48.70±5.64</td>
</tr>
<tr>
<td>4x50 m (10s)</td>
<td>47.85±5.52</td>
<td>47.38±5.76</td>
<td>48.76±5.10</td>
<td>48.92±5.07</td>
<td>48.83±5.25</td>
</tr>
<tr>
<td>4x50 m (20s)</td>
<td>46.51±4.99</td>
<td>46.84±5.35</td>
<td>48.23±5.71</td>
<td>48.30±5.32</td>
<td>47.63±5.23</td>
</tr>
</tbody>
</table>

Values are means ± SD. * Significant difference from 1st, 2nd and 3rd 50m swim (P<0.05).

Furthermore, significant differences in number of strokes were observed between the 1st and 2nd 50m swim of continuous swimming and the 3rd and 4th 50m swim of “broken” swim (Table 3).

Table 3. Number of strokes in each 50m swim (200m, 5, 10 and 20s rest interval).

<table>
<thead>
<tr>
<th>Conditions</th>
<th>1st 50m</th>
<th>2nd 50m</th>
<th>3rd 50m</th>
<th>4th 50m</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>200m</td>
<td>20.83±2.42</td>
<td>20.38±2.19</td>
<td>20.32±2.26</td>
<td>20.32±2.26</td>
<td>20.30±2.23</td>
</tr>
<tr>
<td>4x50 m (5 s)</td>
<td>33.72±3.23</td>
<td>32.62±2.27</td>
<td>31.63±2.28</td>
<td>31.63±2.28</td>
<td>31.62±2.28</td>
</tr>
<tr>
<td>4x50 m (10s)</td>
<td>48.39±4.92</td>
<td>48.00±5.21</td>
<td>48.15±5.14</td>
<td>48.15±5.14</td>
<td>48.14±5.14</td>
</tr>
<tr>
<td>4x50 m (20s)</td>
<td>46.51±4.99</td>
<td>46.84±5.35</td>
<td>48.23±5.71</td>
<td>48.30±5.32</td>
<td>47.63±5.23</td>
</tr>
</tbody>
</table>

Values are means ± SD. * Significant difference from 1st, 2nd and 3rd 50m swim (P<0.05).

According to our results, in “broken” swimming the 20 s. resting interval allowed maintenance of higher speed. This training method has similar physiological responses to those of continuous swimming. Shorter resting intervals do not seem to improve the swimming rate and speed.

The best competition performance is usually achieved when the swimmer maintains the highest constant mean speed throughout the distance. This is accomplished by different training methods. One of them is to divide the total swimming distance in smaller distances during which the swimmer has to swim with the higher speed. This training method is known as the “broken swim” method (Maglischo, 1993) and gives the swimmer the possibility to swim at maximum intensity. Moreover, “broken” swimming stabilizes and improves the time between swimming distance. According to this method, the resting interval could be either long (20 s) or very short (5 s). As it was expected, the given resting interval is not adequate for fatigue substance removal and replenishment of energy sources. Consequently, high swimming speed maintenance with very short resting interval between swims in “broken” swimming may indicate the athlete’s ability to maintain the higher swimming speed with similar physiological load during continuous swimming.

The oxygen consumption was similar at the end of each of 4 exercise conditions either as absolute values or as percentage (%). Also, lactate concentration values and the rate of perceived exertion (Borg 1982, Chen et al. 2002) were similar, regardless of the resting interval and type of effort. This may have contributed to the short interval rest being inadequate to remove lactate acid. The higher heart rate in “broken” swimming with 20 s rest interval compared with continuous swimming shows the greater exercise intensity. It is not known if the intensity would be greater in even longer resting intervals.

Performance characteristics (performance time and mean speed) were greater in “broken” swim with 20 s resting interval than in shorter intervals in the same exercise condition or in continuous swimming. Additionally, as it seems from Table 3, participants in exercise condition with 20 s resting interval maintained the swimming speed and number of strokes constant with non significant differences in time and number of strokes between 50m swims compared with 200m continuous swimming. This supremacy of “broken” swim in maintenance of high swimming speed and in performance time can be explained from the longer rest time of 20 s. As can be seen from heart rate values during recovery time, the participants had significantly lower heart rate in the greater resting interval of 20 s than in intervals of 10 and 5 s (182.72±9.93 vs 190.08±12.42 beat min⁻¹). In contrast to the other swimming conditions of shorter resting interval the resting time of 20 s allowed participants to swim with greater intensity maintaining the speed constant in all parts of the distance. It seems that the better swimming performance and the greater mean speed and heart rate compared with 200m continuous swimming are related to the fact that 50% of phosphocreatine replacement needs 30 seconds of rest while the replacement of O₂ deficit needs about 22 seconds of rest. As a result, these two factors can not be ignored. The 20 s resting time allowed for greater energy replenishment than in shorter resting intervals of 10 and 5s. Moreover, in exercise of high intensity lasting up to 3 minutes such as 200m swimming, together with anaerobic metabolism, the aerobic metabolism is activated. Di Prampero et al. (1970) showed that in exercise of high intensity, the contribution of anaerobic metabolism to the energy production is reduced after 40 s and therefore aerobic metabolism is activated. Consequently, it seems that in swimming conditions of short resting interval the body is overloaded more because the two mechanisms of energy production are fully activated much earlier.

One more explanation that can be given is that the participants perhaps gained a psychological advantage in a long resting time of 20 s as compared with intervals of shorter resting time (10 and 5 s). It seems that the brain is one of the main and possibly the final factor, which determines performance. As a result, the brain via homeostatic mechanisms tries to prevent the systems of the body from failure, which are affected by exercise.
According to our results, the resting interval between swims, in the 4x50m ‘broken’ swim, should be great enough to partly replenish energy sources. Additionally, in ‘broken’ swimming the high speed maintenance capacity is improved when the swimming speed between swims is high and remains constant throughout sets with similar physiological responses as those in continuous swimming. However, the resting interval needed for improving the high speed maintenance capacity may depend on athlete’s fitness level. In this study, the 20 s resting time between swims was adequate while the shorter resting intervals were not enough to maintain the intensity and the swimming speed in levels higher than that of continuous swimming. Consequently, if the interval time between swims is very short, the concrete training target of ‘broken’ swim can not be accomplished. However, shorter resting intervals could be used to overload the swimmers with relatively higher intensity than straight 200m.

The results verified the hypotheses while in some circumstances were differentiated depending on the rest interval. Regardless of the rest interval between swims in ‘broken’ swimming, the maximum lactate concentration and O$_2$ deficit were similar at the end of each condition. The heart rate in the condition of 20 s rest interval was higher than in conditions of shorter rest interval due to the greater exercise intensity. On the contrary, no differences were observed for heart rate, when the resting interval was short (10 and 5 s.). Based on our results, performance improvement in ‘broken’ swimming needed the concrete interval time of 20 s.

The principle limitation of the present study is the sample size. 12 male, young swimmers (14-17 years) participated. The conclusions drawn by the present study can not be generalized for elite swimmers, women and for different swimming style and distance, given the fact that 200m distance and free style swimming were employed.

CONCLUSIONS

The present study has investigated the physiological responses of ‘broken’ swimming (4x50m) with different resting interval compared with those of continuous method (200m) during free-style swimming of maximum intensity. Moreover, the present study examined which specific resting interval in ‘broken’ swimming, contributes to the development of higher swimming speed with similar physiological demands compared to those of continuous swimming. Our findings suggest that the physiological responses of the two methods are similar and ‘broken’ swimming with short resting interval does not give any benefit for swimming speed improvement. Different benefits could be gained from shorter resting intervals. However, it was found that swimmers in ‘broken’ swimming derived a significant benefit from swimming with 20 s resting interval between swims. Particularly, it seems that swimming performance in ‘broken’ swimming needs 20 s resting interval between swims to be developed.

REFERENCES


General Indexes of Crawl Swimming Velocity of Junior Water Polo Players in a Match

Bratusa, F.Z.¹, Perisic, S.M.², Dopsaj, J.M.¹

¹Faculty of Sport and Physical Education, University of Belgrade, Belgrade, Serbia
²UFK Sports Recreational Center Tasmajdan, Belgrade, Serbia

The aim of this research is to define crawl swimming velocity realized by junior water polo players during a match. Over a four year period, 35 water polo players have been observed at the age of 16 years. It was established that there is no statistically significant difference of crawl technique swimming velocity between the quarters of a match (F=1.903, p = 0.127). It was also determined that there are no differences of swimming velocity distribution with regard to quarters (F=5.269, p = 0.153).

The given fact can be a consequence of adaptation to the applied training velocity distribution with regard to quarters (F=5.269, p = 0.153). The obtained results should not be generalized and it does not mean that the same results would be obtained if this category were to be observed on the international level.

Key words: water polo, crawl technique, swimming velocity

INTRODUCTION

Water polo is among those sports with predominantly non stereotypical movements and situations, with a constant change of dynamic and motor behaviour. Water polo has swimming efforts that are predominant in the course of a match (swimming volume, intensity, combination of different swimming techniques and different swimming distances), conditions that require elite water polo players to have developed well all three energy systems, aerobic, alactate and lactate (Pinnington et al., 1988; Dopsaj and Matkovic, 1994; Smith, H. 1999).

A water polo game is not represented only by basic movements (swimming) but also by a great number of specific movements in the water performed in a horizontal and a vertical position. In these positions, a great number of elements of technique with the ball are performed (passing, receiving, shooting on goal), without the ball (pass over, jumps out, blocks), contacts with the opponent player (duels), without contact with opponent player (basic position), (Bratusa at al 2003). All of this indicates the complexity of water polo as well as of the training process itself, regarding better technical and tactical preparation of water polo players.

In the course of a match a water polo player spends around 37% of overall playing time in the horizontal position, and around 90% of the swims the crawl technique is used (Dopsaj and Matkovic, 1994). This indicates that the horizontal position is a less represented activity during a match compared to others. The horizontal position, i.e. movement parallel with the water surface, includes swimming by using crawl, backstroke and breaststroke and combinations of these techniques. The aim of this study is to define the swimming velocity of players in a horizontal position, i.e. crawl technique swimming velocity, realized by junior water polo players during a match, as it is the most represented technique.

METHOD

The motor activity of each selected player was monitored at matches played in the state championship or cup. Only one player was monitored during each match.

By video analysis, all swimming movement phases were registered during a water polo match. By chronometry, the duration of each swim per effort was recorded. The length of the covered distances were determined by the analysis of video recordings and use of markers placed along the outline of the playing area at 2nd, 4th, 7th, 10th, 15th, 20th, 23rd and 28th meter.

The sample consisted of 35 junior water polo players. The players were monitored at the final competitions of championship and cup of Serbia and Montenegro from March 2004 to April 2008. The test encompassed four generations of the junior category (the age of 16). The players were members of the following clubs: Water polo clubs: VK “Partizan”: N=9, VK “Crvena Zvezda” N=6, VK “Beograd”: N=7, VK “Primorac”: N=3, VK “Vojvodina”: N=3, VK “Zemun”: N=2, VK “Nis”: N=2, VK “Becej”: N=1, VK “Jadran”: N=1, and VK “Student” N=1. The criteria for selection were that they were regularly players of the first formation of their teams, playmakers, successful water polo players, and played the most minutes per match. The majority of the players monitored are now members of youth national teams. The variables in this research covered the structure of the crawl technique. The following variables were observed: 1) Average swimming velocity during the match (V<sub>M-crawl</sub> – average crawl technique swimming velocity realized by a player during the match expressed in m·s<sup>–1</sup>), 2) Average swimming velocity per quarter (V<sub>Q-crawl</sub> – average crawl technique swimming velocity realized by a player during the each quarter expressed in m·s<sup>–1</sup>). 3) Distribution of swimming velocity during the match (DV<sub>M-crawl</sub>) – the swims realized by a player at low, moderate, medium, near maximal or maximal velocity during the match, expressed in percentages. 4) Distribution of swims per quarter according to the swimming velocity (DV<sub>Q-crawl</sub>) – covered sections realized by a player at low, moderate, medium, near maximal or maximal velocity during the each quarter, expressed in percentages.

The results were elaborated by descriptive statistical analysis and ANOVA in order to establish differences of the observed variables between the quarters (Hair et al. 1995).

Table 1. Descriptive statistics

<table>
<thead>
<tr>
<th>Quarters</th>
<th>m·s&lt;sup&gt;–1&lt;/sup&gt;</th>
<th>m·s&lt;sup&gt;–1&lt;/sup&gt;</th>
<th>(%)</th>
<th>95% Confidence Bound</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>m·s&lt;sup&gt;–1&lt;/sup&gt;</th>
<th>m·s&lt;sup&gt;–1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>500</td>
<td>1.385</td>
<td>.358</td>
<td>25.86</td>
<td>1.354</td>
<td>1.416</td>
<td>.667</td>
<td>3.226</td>
</tr>
<tr>
<td>2.00</td>
<td>398</td>
<td>1.343</td>
<td>.363</td>
<td>27.00</td>
<td>1.307</td>
<td>1.379</td>
<td>.605</td>
<td>3.008</td>
</tr>
<tr>
<td>3.00</td>
<td>425</td>
<td>1.353</td>
<td>.357</td>
<td>26.42</td>
<td>1.319</td>
<td>1.387</td>
<td>.595</td>
<td>2.979</td>
</tr>
<tr>
<td>4.00</td>
<td>359</td>
<td>1.331</td>
<td>.328</td>
<td>24.67</td>
<td>1.297</td>
<td>1.365</td>
<td>.660</td>
<td>2.727</td>
</tr>
<tr>
<td>Total</td>
<td>1682</td>
<td>1.356</td>
<td>.353</td>
<td>26.06</td>
<td>1.339</td>
<td>1.372</td>
<td>.595</td>
<td>3.226</td>
</tr>
</tbody>
</table>

RESULTS

Table 1 displays the values of basic descriptive statistics of average swimming velocity during the match and per quarter. The average swimming velocity realized by the observed water polo players during the match was 1.356±0.353 m·s<sup>–1</sup>, and per quarter – in the first quarter 1.385±0.350 m·s<sup>–1</sup>, in the second quarter 1.343±0.362 m·s<sup>–1</sup>; in the third quarter 1.353±0.357 m·s<sup>–1</sup> and in the fourth quarter 1.331±0.328 m·s<sup>–1</sup> (Figure 1).

Figure 1. Average swimming velocities per quarter by intensity category
With regard to the structure of swimming velocity in the match, the results indicated that the players observed realized maximal velocity for 2.3% of the swims (at >1.886 m/s) (Figure 2), at near maximal velocity 30.6% of the swims (at >1.533 m/s-1<1.885), medium velocity 43.9% of the swims (at >1.179 <1.532 m·s-1), moderate velocity 15% of the swims (at >1.179 <1.532 m·s-1) and low velocity 8.1% swims (at V<0.825 m·s-1) (Table 2).

### Table 2. Reliability interval

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Interval velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximal</td>
<td>1.886 and faster</td>
</tr>
<tr>
<td>near maximal</td>
<td>1.533 1.885</td>
</tr>
<tr>
<td>medium</td>
<td>1.179 1.532</td>
</tr>
<tr>
<td>moderate</td>
<td>0.826 1.178</td>
</tr>
<tr>
<td>low</td>
<td>0.825 and slower</td>
</tr>
</tbody>
</table>

With regard to the structure of swimming velocity in the match, the results indicated that the players observed realized maximal velocity for 2.3% of the swims (at >1.886 m/s) (Figure 2), at near maximal velocity 30.6% of the swims (at >1.533 m/s-1<1.885), medium velocity 43.9% of the swims (at >1.179 <1.532 m·s-1), moderate velocity 15% of the swims (at >1.179 <1.532 m·s-1) and low velocity 8.1% swims (at V<0.825 m·s-1) (Table 2).

**DISCUSSION**

The results of this research indicated that over 70% of the swims in which a player uses the crawl technique were realized at high and medium intensity. The reliability interval (Table 2) indicates that these water polo players swim mostly from 1.179 m·s-1 to 1.885 m·s-1.

Since the analyses showed that there is no statistically significant difference between the swimming velocities per quarter, and there is no statistically significant difference in velocity distribution per quarter in junior water polo players, that indicates that players did not change rhythm during the match. The velocities at which the players most often swim using crawl technique were, medium velocity from 1.179 m·s-1 to 1.885 m·s-1 (43.9%) which indicates predominantly aerobic swimming regimes, and velocities from 1.533 m·s-1 to 1.885 m·s-1 (30.6%) which indicates aerobic/anaerobic swimming regimes, and that a change of rhythm requires more swims at maximal intensity, which is represented here with only 2.3% of the swims.

Non-existence of difference of swimming velocities, as well as of swimming velocity structure between the quarters can result from adaptation of players to uniform training regime, i.e. insufficient adaptation to increased demands in the game with necessary change of rhythm. On the other hand, constant playing rhythm can be the consequence of the tactics implemented by the observed players, i.e. game system applied by the clubs of these players.

**CONCLUSION**

During a water polo game for junior age players it was established that the average swimming velocity is without statistically significant oscillations. The non-existence of significant rhythm change may have several possible causes which affect the structure of swimming velocity. For a rhythm change, it is necessary that the players have, apart from aerobic capacity, a well developed glycolytic-lactate mechanism of energy production. As the observed players are juniors, aged 16 and younger, it is possible that there is a greater adaptation to predominantly aerobic training loads, i.e. the observed players are still not in the phase of specific training for intensification of training work at a level of glycolytic load.

Certain tactical requests by coaches can also affect a relatively small change of rhythm during the match. Great number of duels and static play without short and fast swims realized in the space between the goals at distances not exceeding 15m can certainly influence small change of rhythm during the match.

The research was carried out on the national level and cannot be generalized with regard to the international level of competition in junior age competition.

**REFERENCES**


Bench Press and Leg Press Strength and its Relationship with In-Water Force and Swimming Performance when Measured in-season in Male and Female Age-group Swimmers

Carl, D.L., Leslie, N., Dickerson, T., Griffin, B., Marksteiner, A.

University of Cincinnati, Cincinnati Ohio, USA

The purpose of this study was to determine if two standard measurements of dry land strength would correlate with the ability to generate in-water force. Participants were 25 male and female age-group swimmers. One repetition max lifts were established for the Bench Press (BP) and Leg Press (LP) and correlated with in-water force generation as measured during tethered swimming (TeS). They were also correlated with swimming performance using a timed 22.9-m (25y) swim. A significant correlation existed between BP strength and both TeS and 25y tests (r = 0.82 and 0.84 respectively, p< 0.01). A minor correlation existed between LP and 25y (R = 0.70, p< 0.01). No significant correlation existed between LP and TeS (r= 0.50, p< 0.01). In addition, males demonstrated stronger correlations than females in all cases. In conclusion, BP strength may be an appropriate alternative to established methods as an indicator of in-water force generation and swimming performance in older age-group swimmers.

Key words: Swimming, Tethered swimming, Bench Press, Leg Press

INTRODUCTION

In recent years, USA-Swimming launched a series of educational programs and databases designed to quickly and efficiently disseminate information to their entire coaching membership. One such program is the Land / Water Strength Test (LWST; Sokolovas, 2007 and USA-Swimming, 2007) database. The purpose of the LWST is to assess swimming-specific strength on land and to determine how effectively it transfers into the generation of force while in the water. Depending upon the relationship observed, a coach could make personalized adjustments in the swimmers strength training program and or their stroke efficiency. If the relationship is high between land and water strength then it might be suggested that the coach design a resistance training program to enhance overall strength in an effort to improve performance. Conversely, if the relationship is low it would be desirable for the coach and athlete to focus on correcting stroke efficiency, more so, than the overall strength of the swimmer.

To assess dry land strength, USA-Swimming recorded maximum effort strength during isometric contractions on a Vasa Trainer swim bench. To our knowledge, additional testing measures have not been conducted to determine whether other forms of land strength are equally beneficial in establishing discrepancies between land and in-water strength measurements. Therefore, it was the purpose of this study to determine if two standard measurements of dry land strength, bench press (BP) and leg press (LP), would correlate with the ability to generate force in water, as measured during tethered swimming, and whether they would correlate with sprint swimming performance as measured by a timed 22.9m swim.

METHODS

Twenty five (10 male, 15 females) highly competitive age-group swimmers ranging from National qualifiers to High School competitors volunteered to participate in the study. Their mean (± SD) age, weight and height were 16.6 ± 1.3 years, 71.6 ± 17.3 kg, and 181.6 ± 3.8 cm for males and 16.3 ± 0.9 years, 62.0 ± 2.9 kg, and 168.2 ± 4.6 cm for females respectively. Each participant in the study trained on a year-round basis. The study was approved by the institutional review board at the University of Cincinnati with all subjects completing an informed consent document.

Each subject completed a single day testing session that consisted of a randomized distribution of the following activities:

Swim Training: Prior to the in-water testing, each subject completed a standardized 1371-m warm-up. Completion of the 2 in-water tests was completed in randomized order. 22.9-m Swim Test: Each subject completed two 22.9-m maximal effort swims from the starting block. Each swim was separated by a minimum of 5 minutes. Active recovery swimming was allowed at the discretion of each subject. Times were recorded to the 100th of a second and the two trials were averaged for best time and recorded. Tethered maximal effort swim: Each subject completed two in-water tethered maximal force generation swims (Digital Force Gauge, IMADA, Inc). Each subject was instructed to go all out from a push for 10 seconds. Maximal force generated was recorded in Newton’s and the two trials averaged for best effort and recorded. Each trial was separated by a minimum of 1 minute rest.

Resistance Training: Prior to the land testing each subject participated in some light lifting for the benefit of warming up. Completion of the two land strength tests was completed in randomized order. Bench Press: Subjects completed a standard barbell chest press to determine a one repetition maximum (1RM). The following protocol was established. Each subject began with a warm up set consisting of light weight for 10-15 repetitions. Subjects then completed a set of moderate weight for 10 repetitions followed by a minimum of 2 minutes rest. The weight was increased by 10-20 % and another set of 10 repetitions was completed. This procedure was continued until the subject was unable to complete ten full repetitions. 1RM BP was estimated using the following equation (Bryzcki 1993): Lifting weight (in pounds) / (1.0278-(.0278 x no. of reps)). Leg Press: To establish a 1RM LP, subjects completed a bilateral seated leg press following the same established protocol (Bryzcki 1993) that was used for the 1RM BP.

Descriptive statistics (mean and SD) were calculated for subjects characteristics (age, height, and weight). Pearson’s product moment correlation coefficient (r) was used to explore the relationships among different variables. The level of significance was set at p ≤ 0.01.

RESULTS

Table 1 summarizes the correlation coefficients for each of the variables measured. A significant correlation was found to exist between BP strength and both the TeS and the 22.9m swim respectively (r = 0.82 & 0.84). The relationship between BP and TeS and between BP and 22.9m swim time is shown in figures 1 and 2 respectively.

The correlation between LP and the 22.9-m swim time was not as strong as the BP (r = 0.70). In addition, no significant correlation existed between LP and TeS force generated. However, further analyses revealed that when the males were separated from the females, significant correlations were found between all variables measured in both testing sessions including LP vs TeS (Table 1).

Table 1. Mid season r-values for correlation between land strength and in-water force generation measurements. P < 0.01; BP bench press, LP leg press, 25 22.9-m swim, TeS tethered swim. Bold indicates significant correlation.

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Combined</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP vs 25</td>
<td>0.702409</td>
<td>0.752053</td>
<td>0.232553</td>
</tr>
<tr>
<td>LPrel vs 25</td>
<td>0.279929</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LP vs TeS</td>
<td>0.504378</td>
<td>0.708448</td>
<td>0.282953</td>
</tr>
<tr>
<td>LPrel vs TeS</td>
<td>0.0782</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BP vs TeS</td>
<td>0.819576</td>
<td>0.732068</td>
<td>0.560393</td>
</tr>
<tr>
<td>BPrel vs TeS</td>
<td>0.694141</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BP vs 25</td>
<td>0.841623</td>
<td>0.871575</td>
<td>0.387719</td>
</tr>
<tr>
<td>BPrel vs 25</td>
<td>0.813758</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION

The relationship between various power measurements and swimming performance has been well established (Sharp et al., 1982; Hawley et al., 1992 & Swaine (1994). Often measured using a modification of the Wingate Anaerobic test, what has not been established to our knowledge is the relationship between swimming performance and more practical forms of general strength. Following the protocols established by USA-Swimming’s Land / Water Strength Testing, a common measurement of strength, the 1RM BP, can be used with success when addressing imbalances between land strength and swimming performance. With the relative ease associated with the measurement of a 1RM BP, this protocol may be more readily usable for a majority of swimming programs.

Although the correlation data for the 1RM leg press was not as strong as the bench press it too may be useful in developing an overall individualized picture of a swimmer. The combination of the two measurements would allow a coach to look at both upper and lower body strength separately and in combination as they translate to swimming performance. Although not a part of this study, the USA-Swimming protocol includes a kicking component and therefore the measurement of LP strength warrants further investigation into its potential effectiveness. Interestingly, when separating the females from the males in this study, weaker correlations were observed for all measurements taken. It is believed that this discrepancy may have been the result of the males having a greater amount of muscle mass than their female counterparts (Carter & Ackland 1994). In addition, there may have been more familiarity with strength training for the males than the females and this may have had an effect on the measurements of each subject's 1RM's. Also, this could have been due to greater homogeneity within each group. Participant group heterogeneity/homogeneity can affect the correlations like these.

In addition, the data revealed similarity between the mid season and the post season testing sessions for all measurements taken. It is our belief that this lends support to the usefulness of this type of strength testing. This may indicate that regardless of the stress levels associated with training, the relationship between land strength and in-water force generation is strong and is relevant throughout the entire swimming season including through the taper period.

**REFERENCES**


Effect of Start Time Feedback on Swimming Start Performance.

de la Fuente, B.1 and Arellano, R.2

1Sierra Nevada High Performance Altitude Training Centre, Monachil, Spain.
2University of Granada, Granada, Spain.

The start is a significant component in competitive swimming performance, particularly in the short events. This relevance is confirmed when the differences in the start times are greater than the differences in the event’s final times. The purpose of this study was to determine how start time feedback during training might improve a swimmer's start performance. A group (n=42) of regional swimmers and P.E. Students (former competitive swimmers), participated in the study. The main group was equally divided related to 15m performance and gender into experimental and control groups. After ten sessions of specific start training, both groups improved their starting times (average improvements: EG: 0.30 s vs CG 0.11 s). However, greater improvements were produced within the experimental group (15m: p<0.01 vs p<0.05 and 10m: p<0.001 vs p<0.01). In addition, performance tended to be more consistent within this group (lower differences between the best time and the average in almost every session).

Key words: Swimming Start Training, Immediate Feedback, Performance Improvement

INTRODUCTION

The start is a significant component in competitive swimming performance, particularly in the short events (Zatsiorsky, et al., 1979), even more so in short-course competitions. Sometimes, the difference between the winner and the last finalist can be less than the difference in start time. Therefore the start may be the key factor to winning or losing a swimming race (Arellano, 1990). In addition, it is important to take into account the psychological advantage that can result from emerging to the surface among the leaders (Arellano, 1990; Miller et al., 2002). Moreover, surfacing ahead allows the swimmer to avoid the wave drag produced by the rest of the competitors in the first lap of the race. All these considerations highlight the importance of the start and consequently of start training.

It is commonly known that the start performance is not as related to physiological factors as the swim phase. For starters, the level of motor skill controls the movements, and consequently these skills should be trained. During the swimming start, there is no external stimulus other than the acoustic signal, so it is a self-controlled task, not influenced by environmental disturbances. According to Knapp (1963), the start can be considered a “closed skill”, with the movement controlled by proprioceptive sensory information as there is lack of external information. During the training sessions.

The purpose of this study was to determine how improvement of the swimmer's start could be related to giving the swimmer accurate feedback about the start duration. Nevertheless, due to the shortness of the duration of this technique, accurate measurement must be made in order to avoid false improvements due to erroneous measurement. Prior to the study, differences between manual timing and times obtained through video analysis were examined. The differences found (average 0.52s, p<0.001) highlighted the importance of an accurate evaluation during the training sessions.

METHODS

Subjects: A group of 31 male and 11 female regional swimmers and P.E. students (former competitive swimmers), participated in the study (see Table 1). The main group was equally divided (n=21) into experimental and control groups, keeping the initial ratio related to gender, level of performance and impulse force recording.

Each swimmer performed 60 start trials distributed over 10 sessions. Gliding, underwater kicking or freestyle swimming followed the start until the swimmer reached an electronic touchpad placed at either 10m or 15m from the start, depending on the sessions’ content. The rest period between trials was long enough to avoid the swimmers performing any start with a higher heart rate than the previous one.

The experimental group (EG) received accurate information about their starting time about 5 seconds after ending each start execution (Terminal Knowledge of Results [TKR]). The control group (CG) did the same start training but did not receive any information after each trial.

Table 1. Means and standard deviation for subjects' age, mass and height.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>31</td>
<td>11</td>
</tr>
<tr>
<td>Age (years)</td>
<td>23.88</td>
<td>22.95</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>72.97</td>
<td>57.89</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.52</td>
<td>162.41</td>
</tr>
</tbody>
</table>

*** Gender differences p<0.001

Material: The system developed allowed swimmers and coaches to know the starting times as accurately as in competitions where a race analysis is performed (see www.swim.ee or http://www.minorisa.org/fes/dades/finabcn03/). It consisted of an ALGE electronic touchpad, (80 cm x 90 cm), hanging inside a stainless-steel structure specifically built for the study (see Figure 1). The structure was designed in such a way that it could be used on either side of the swimming pool.

During the typical swim race analysis performed by video analysis the swimmer’s head is the reference event that determines start time. In this study, as time was determined by an electronic clock, the start time was set when the hands stopped the timer by contacting a touchpad, similar to competition.

The touchpad was connected to a device that activates the acoustic signal. The touchpad structure had to be placed an arms length further from the start, so that when the hand comes in contact with it, the head will be close to the 10m or 15m distance typically used for start testing. This distance was set at 0.50 m for this and other studies (Wirtz, et al., 1992; Sánchez, 2000) according to Haljand’s (2002) criteria on defining finish time of the start.

The touchpad was designed in such a way that it could be used in both directions.

The purpose of this study was to determine how improvement of the swimmer's start could be related to giving the swimmer accurate feedback about the start duration. Nevertheless, due to the shortness of the duration of this technique, accurate measurement must be made in order to avoid false improvements due to erroneous measurement. Prior to the study, differences between manual timing and times obtained through video analysis were examined. The differences found (average 0.52s, p<0.001) highlighted the importance of an accurate evaluation during the training sessions.

METHODS

Subjects: A group of 31 male and 11 female regional swimmers and P.E. students (former competitive swimmers), participated in the study (see Table 1). The main group was equally divided (n=21) into experimental and control groups, keeping the initial ratio related to gender, level of performance and impulse force recording.

Each swimmer performed 60 start trials distributed over 10 sessions. Gliding, underwater kicking or freestyle swimming followed the start until the swimmer reached an electronic touchpad placed at either 10m or 15m from the start, depending on the sessions’ content. The rest period between trials was long enough to avoid the swimmers performing any start with a higher heart rate than the previous one.

The experimental group (EG) received accurate information about their starting time after 5 seconds after ending each start execution (Terminal Knowledge of Results [TKR]). The control group (CG) did the same start training but did not receive any information after each trial.

Table 1. Means and standard deviation for subjects' age, mass and height.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>31</td>
<td>11</td>
</tr>
<tr>
<td>Age (years)</td>
<td>23.88</td>
<td>22.95</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>72.97</td>
<td>57.89</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.52</td>
<td>162.41</td>
</tr>
</tbody>
</table>

*** Gender differences p<0.001

Material: The system developed allowed swimmers and coaches to know the starting times as accurately as in competitions where a race analysis is performed (see www.swim.ee or http://www.minorisa.org/fes/dades/finabcn03/). It consisted of an ALGE electronic touchpad, (80 cm x 90 cm), hanging inside a stainless-steel structure specifically built for the study (see Figure 1). The structure was designed in such a way that it could be used on either side of the swimming pool.

During the typical swim race analysis performed by video analysis the swimmer's head is the reference event that determines start time. In this study, as time was determined by an electronic clock, the start time was set when the hands stopped the timer by contacting a touchpad, similar to competition. For this reason the touchpad structure had to be placed an arms length further from the start, so that when the hand comes in contact with it, the head will be close to the 10m or 15m distance typically used for start testing. This distance was set at 0.50 m for this and other studies (Wirtz, et al., 1992; Sánchez, 2000) according to Haljand's (2002) criteria on defining finish time of the start.

The touchpad was connected to a device that activates the acoustic signal. The touchpad structure had to be placed an arms length further from the start, so that when the hand comes in contact with it, the head will be close to the 10m or 15m distance typically used for start testing. This distance was set at 0.50 m for this and other studies (Wirtz, et al., 1992; Sánchez, 2000) according to Haljand's (2002) criteria on defining finish time of the start.

The touchpad was connected to a device that activates the acoustic signal. The touchpad structure had to be placed an arms length further from the start, so that when the hand comes in contact with it, the head will be close to the 10m or 15m distance typically used for start testing. This distance was set at 0.50 m for this and other studies (Wirtz, et al., 1992; Sánchez, 2000) according to Haljand's (2002) criteria on defining finish time of the start.
RESULTS
The change in start times did not display significant differences between groups. However, data showed that both groups reduced their starting times, even the group that did not receive feedback after the effort (Average improvements: EG: 0.30 s vs CG 0.11 s). The fact that the CG group improved due to practice without feedback may explain the lack of significant differences between the improvements in the EG and CG. However, the improvements were greater within the EG (5.2%) than control (2.2%), where the swimmers received TKR after the practice. In order to check the significance of the improvement within each group, a related samples t-Test was performed. Results showed significant differences in both groups, with a greater significance level in the EG, at the four distances analyzed (Table 2).

At the previous video recording, most swimmers emerged to the surface before 10 m. For that reason, the decision was made to focus the training on 10 m rather than 15 m, in order to avoid an erroneous start measurement related to the swim phase after surfacing. Taking into account the total number of repetitions, the performance improvement was greater at the more practiced distances (start followed by freestyle swimming up to 10 m and start followed by underwater dolphin kicking up to 10 m) (Table 2).

Table 2. Differences between pre-test and post-test in both groups (Experimental – EG and control group CG). Results from related samples t-Test.

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-Test</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (s)</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>EG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 m free</td>
<td>8.02</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>10 m DK</td>
<td>5.68</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>10 m free</td>
<td>4.84</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>10 m glide</td>
<td>7.18</td>
<td>1.11</td>
<td></td>
</tr>
<tr>
<td>CG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 m free</td>
<td>8.17</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>10 m DK</td>
<td>5.84</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>10 m free</td>
<td>4.95</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>10 m glide</td>
<td>7.41</td>
<td>1.11</td>
<td></td>
</tr>
</tbody>
</table>

1. Free. Start followed by freestyle swim until 15 m  
2. DK: Underwater dolphin kicking.  
3. Start + Gliding until hands contact (TPI) at 10 m.

To represent the effectiveness of the experimental training, the start improvement as a percentage between the times achieved before and after the training sessions was calculated. As a result, the improvement percentage was 3% greater in the experimental group, with greater differences on the more practiced distances (Figure 2). This seems to indicate that giving accurate feedback related to the start duration produces more significant effects than just systematic repetition.

Figure 1. Specifically designed structure to support the electronic ALGE touchpad (TPI), to be placed at any distance from the wall on either side of the 25 m or 50 m pool.

Figure 2. Percentage improvement in start times before and after training in the experimental and control groups.

As a consequence of the statistical results, the data for individual swimmers were analysed. The starting times as a function of the number of training sessions for two subjects; the one with greatest improvement and the one with the least improvement for both groups were examined (Figure 3). Comparing times, (Figure 4) it was seen that performance tended to be more consistent within the EG (lower differences between the best time and the average time among the sessions). Similar times seem to indicate a more constant and uniform performance at the end of the training period.

Figure 3. Individual performance evolution (10m Free) along the sessions.
Figure 4. Examples from four subjects of each group. Differences between best time and average time trial before and after the practice.

DISCUSSION

Results suggest that the systematic repetition of the start leads to improvement in performance and that providing feedback to the swimmer resulted in greater improvement. This should be taken into account in training by increasing the practice of starting within the year's planning. Different studies had shown that jumping ability was not related to the total start performance (Fuente, et al., 2003) nor is nine weeks of strength training (Breed, et al., 2003). There seems to be no direct transfer of strength or jumping skills to the swim starts. This finding further supports the need to adapt the motor control mechanisms of the diving techniques by practicing them in parallel with resistance training (Bobbert, et al., 1994). Furthermore it is recommended to increase the total number of start repetitions during the training sessions.

Importantly, giving the swimmers accurate knowledge of results produces greater performance improvements than merely systematic repetition. At the end of the movement, swimmer’s proprioceptive information is contrasted with the external data input (start time or distance) to improve and to optimize the motor schema. Information obtained as a result of the start times can then be compared to the expected objectives of the swimmer and to refine future skill development (Oña, et al., 1999). The information about the start duration offered by the system, by itself, seems to be useful for the swimmers, so that they can internally compare their execution with the result and for refining the future start skill. In addition, the system seems to be more effective for the individual, making the start performance more consistent. This is important when considering the performance expected at important competitions. Finally, as Mason suggests, the coach should ensure appropriate training with similar conditions to competition (Mason, 1999).

CONCLUSION

The systematic and controlled repetition of the start technique produces an improvement in performance. This should be taken into account by increasing the start practicing time within the whole year’s planning. Moreover, the system developed for giving accurate information about the start’s duration during the practice seems to be more effective in reducing the starting times than the standard repetition.

Accurate and precise knowledge of results at the end of the execution made the individual performance more consistent, reducing the differences between trials and tending to decrease the starting times. These data suggest that increasing the start practice time within the year’s planning would benefit the swimmer.

REFERENCES


Predictors of Performance in Pre-Pubertal and Pubertal Male and Female Swimmers

Douda, H.T.¹, Toubeakis, A.G.², Georgiou, Ch.³, Gourgoulis, V.⁴, and Tokmakidis, S.P.¹

¹Democritus University of Thrace, Komotini, Greece
²Kapodistrian University of Athens, Athens, Greece

The predictors of the 50 m front-crawl performance were examined in 72 pre-pubertal and pubertal swimmers. They underwent a battery of anthropometric, body composition and muscle strength measurements. A Principal Component Analysis showed that the Component-1 [Anthropometric-Tethered Swimming Force (TSF)] explained 65.1% of the total variance, Component-2 [Body Composition] 14.6% and Component-3 [Body Dimension] 8.2% respectively. Also, Component 1 was significantly correlated with performance (r=-0.71, p<0.001). When multiple regression models were applied to the pre-pubertal swimmers 90.9% of the variation was explained by the average TSF and arm circumference. Selected anthropometric characteristics and specific strength are important determinants of sprint performance and may have practical implication for both training and talent identification in swimming.

Key-words: Kinanthropometry, Tethered Swimming Force, Performance, Growth

INTRODUCTION

Swimming is a demanding sport and swimmers should be in good condition, including muscular force in order to achieve successful performance. Arm span as well as VO₂peak appear to be the major determinants of front-crawl swimming performance in young swimmers (Jurimae et al., 2007) and muscle force is related to sprint swimming velocity (Yeater et al., 1981). Moreover, grip strength and thigh flexion strength did not differ from that of specialist tennis players in preadolescent male and female swimmers and swimmers did also possess greater leg and arm extension strength (Bloomfield et al., 1986).

Successful performance requires years of practice, usually starting at an early age and it takes about 8 to 10 years of strenuous training for a beginner to reach a competitive status among elite-level athletes. To study the specific changes during this period, however, is not easy since the adaptations to exercise training depend on many interrelated factors, including the initial level of training intensity, age, genetic make up, structural dimensions, body fat levels and body fat distribution (Bailley & Mirwald, 1986). In addition, during this developmental period, growth causes changes in body size (Douda et al., 2002), which cannot be controlled. Therefore, these two factors - growth and swim training - must be taken into consideration when physique is evaluated, body composition and muscle strength of swimmers. It is quite difficult to differentiate activity-related changes from those associated with normal growth and maturity. Linear body measurements (e.g. height, leg length) tend to have a higher genetic influence than circumferences, skinfolds and body mass, which can be influenced by training as a result of adaptive processes (Malina, 1986). In swimming, there is limited published information on the relationship between anthropometry, muscle strength and sprint swimming performance in swimmers during adolescence (Geladas et al., 2005; Pyne et al., 2006).

The purpose of this study was to identify the anthropometric, body composition and strength characteristics as predictors of 50 m front-crawl swimming performance in pre-pubertal and pubertal male and female swimmers.

METHODS

A total of seventy-two swimmers (n=72), were divided into two groups, pre-pubertal (n=30) aged 10.5±0.5 yrs and pubertal (n=42) aged 13.7±1.5 yrs. The swimmers were members of a local swimming club and they trained regularly for 5.97±2.34 yrs. All subjects and their parents were informed about the study and signed a written consent form to participate. Age was computed from the date of birth and date of examination. Using the techniques described by the Anthropometric Standardization Reference Manual (Lohman et al. 1988), height, body mass, sitting height, arm span, skin-fold thickness over the triceps and calf regions, thirteen circumferences (shoulder, chest, waist, abdominal, buttocks, thigh proximal/mid-thigh/distal, calf, ankle, arm, forearm, wrist) and nine diameters (biacromial, chest, depth chest, biiliac, bitrochanteric, knee, ankle, elbow, wrist) were measured. The sitting and standing height ratio was obtained according to the formula (Caldarone et al., 1986): Sitting height (cm) X 100 / Height (cm). Percent body fat was assessed using the equation of Slaughter et al. (1988).

Hand grip strength was measured using a digital hand dynamometer (T.K.K. 5401 Grip-D; Takey, Tokyo, Japan), and the scores were recorded in kilograms. The subject holds the dynamometer in the right hand by the side of the body. The handle of the dynamometer was adjusted if required and the base should rest on first metacarpal while the handle should rest on middle of four fingers. When ready the subject squeezed the dynamometer with maximum isometric effort, which was maintained for about 5 seconds. No other body movement was allowed. The subject was strongly encouraged to give a maximum effort. The reported precision of the dynamometer was 0.1 kg (Espapa et al., 2008).

Tethered swimming force was evaluated during a 30 s test. Each test started with slow swimming and with countdown from three. The swimmers applied maximum intensity after the examiner’s command and the start always coincided with the entry of the right hand. During tethered swimming tests a piezoelectric force transducer connected to an analog digital (A/D) converter system (MuscleLab, Ergotest) with a sampling frequency 100Hz was used for force measurement. The front crawl style was used for all tests. A standard warm-up was used before each test.

Swimming performance was defined as the maximal 50-m front-crawl swimming scores in official national competitions which were obtained by the subjects. Descriptive statistics (means, standard deviations, range) were applied for all variables. In order to quantify the dimensions supposed to underlie performance on a variety of tasks and reduce the initial set of variables, the Principal Components Analysis (PCA) was applied. This procedure was performed on 45 variables for the total sample of 72 swimmers. The coefficient display format was suppressed with absolute values less than the specified value (0.50). Also, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was equal to 0.799 and the Bartlett’s test of sphericity was significant (p < 0.001). In addition, a multiple regression procedure was used to determine the amount of variance in performance swimming scores using the components derived from PCA. Multiple regression models were also applied, using selected variables in order to determine the amount of variance in performance ranking scores in each group separately (pre-pubertal and pubertal). Pearson’s correlation was used to determine the relationship between the three components and the performance competitive scores. Further, the differences between pre-pubertal and pubertal athletes were determined using T-tests. An α level less than 0.05 was used as a criterion for significance.

RESULTS

The results of the Independent T-tests between pre-pubertal and pubertal swimmers are presented in Table 1. The analysis of data indicated that both groups presented different values in the majority of the variables except for body fat, sitting/standing height ratio and BMI values. Correlation coefficients between each variable, performance scores of pre-pubertal (n=30), pubertal (n=42) and total sample (n=72) are also presented in Table 1. The highest correlation in the total sample was found in average tethered swimming force (r=-.81), height (r=.73) and arm-span (r=-.72). Figure 1 shows the correlation coefficients for aver-
age tethered swimming force in the total sample (Figure 1a) for both pre-pubertal (Figure 1b) and pubertal athletes (Figure 1c). In addition, the majority of anthropometric variables were significantly related to performance in pubertal swimmers.

From the PCA analysis, three components were extracted and were labelled in the following order: Component-1: Anthropometric-Tethered Swimming Force (TSF), Component-2: Body Composition and Component-3: Body Dimension. Variables were well defined and their communalities ranged between 0.70 and 0.98. In addition, based on the loading of variables on the three components, the percentage of cumulative variance explained the 88% of the performance score. A multiple regression procedure was used to determine which components were significant predictors of the maximal 50-m front-crawl swimming score (Table 2). Correlation coefficients between the above three factors and the performance swimming score revealed that, in the total sample, the anthropometric and TSF were significantly correlated with performance (r=-0.71, p<0.001). When the multiple regression models were applied to the pre-puberl swimmers (r=0.27,42-0.420*TSF+1.01*circ. arm), 90.9% of the variation was explained by the average TSF and arm circumference while in pubertal swimmers (r=-.38.661-0.111*TSF), 70.4% of the variation was explained only by the average TSF.

**DISCUSSION**

According to the PCA procedure applied in the present study, successful performance in swimming depends on a three-component model including a) anthropometric characteristics and tethered swimming force, b) body composition and c) body dimensions. Knowledge of the importance of these components is helpful for coaches who invest time and effort to create training programs. One of the major findings, however, is that swimming performance scores can be significantly explained by anthropometric and muscle strength components and it should be noted that the latter was identified as the first predictor in both groups of athletes.

Table 1. Results (mean±SD) of Independent T-tests and correlations coefficients among the anthropometric, strength measurements and performance score of the total sample and in each group separately (pre-pubertal and pubertal swimmers).

<table>
<thead>
<tr>
<th>Independent T-tests</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-pubertal (n=30)</td>
</tr>
<tr>
<td><strong>Anthropometric measurements</strong></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>146.5±7.4</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>41.0±6.8</td>
</tr>
<tr>
<td>Arm span (cm)</td>
<td>145.9±8.7</td>
</tr>
<tr>
<td>Sitting/standing height ratio</td>
<td>50.9±1.6</td>
</tr>
<tr>
<td>Biacromial breadth (mm)</td>
<td>32.6±2.0</td>
</tr>
<tr>
<td>Chest breadth (mm)</td>
<td>23.7±1.2</td>
</tr>
<tr>
<td>Shoulder circumference (cm)</td>
<td>85.7±5.1</td>
</tr>
<tr>
<td>Chest circumference (cm)</td>
<td>69.8±6.3</td>
</tr>
<tr>
<td>Arm circumference (cm)</td>
<td>20.6±2.0</td>
</tr>
<tr>
<td>Mid-thigh circumference (cm)</td>
<td>40.8±3.9</td>
</tr>
<tr>
<td>Calf circumference (cm)</td>
<td>29.7±1.9</td>
</tr>
<tr>
<td><strong>Body Composition measurements</strong></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>19.0±3.0</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>8.3±4.4</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>33.1±5.3</td>
</tr>
<tr>
<td><strong>Tethered Swimming Force</strong></td>
<td></td>
</tr>
<tr>
<td>Average Swimming Force (N)</td>
<td>27.2±12.2</td>
</tr>
<tr>
<td>Maximum Swimming Force (N)</td>
<td>97.2±33.7</td>
</tr>
<tr>
<td>Hand grip (kg)</td>
<td>8.9±3.4</td>
</tr>
</tbody>
</table>

Table 2. Results of the multiple regression procedure using the three components of PCA as predictors of swimming performance score.

<table>
<thead>
<tr>
<th>Components</th>
<th>Multiple R</th>
<th>B</th>
<th>β</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Component 1:</strong> Anthropometric-TSF</td>
<td>-.72</td>
<td>-3.08</td>
<td>-.714</td>
<td>-5.63</td>
<td>.001</td>
</tr>
<tr>
<td><strong>Component 2:</strong> Body Composition</td>
<td>.28</td>
<td>1.07</td>
<td>.202</td>
<td>1.59</td>
<td>.123</td>
</tr>
<tr>
<td><strong>Component 3:</strong> Body dimensions</td>
<td>.02</td>
<td>.098</td>
<td>.018</td>
<td>.14</td>
<td>.885</td>
</tr>
</tbody>
</table>

Anthropometric: Height (cm), Weight (kg), Arm-span (cm), Biacromial breadth (mm), Chest breadth (mm), Shoulder circumference (cm), Chest circumference (cm), Mid-thigh circumference (cm), Calf circumference (cm), Tethered Swimming Force (TSF). Average Swimming Force (N), Maximum Swimming Force (N), Hand grip (kg). Body composition: BMI (kg/m²), Body Fat (%), Lean Body Mass (kg). Body dimensions: Sitting and standing height ratio.
It is important to point out that these findings must be taken into consideration especially by coaches and may have practical implications for both training and talent identification in swimming. Moreover, the measurement of TSF should be a useful indicator for monitoring pre-pubertal and pubertal male and female swimmers performance and could be used to evaluate the training process. TSF, arm-span and arm circumference appear to be the major determinants of the 50 m front-crawl performance in young swimmers.

**CONCLUSION**

It is important to point out that these findings must be taken into consideration especially by coaches and may have practical implications for both training and talent identification in swimming. Moreover, the measurement of TSF should be a useful indicator for monitoring pre-pubertal and pubertal male and female swimmers performance and could be used to evaluate the training process. TSF, arm-span and arm circumference appear to be the major determinants of the 50 m front-crawl performance in young swimmers.

**REFERENCES**


**Changes of Competitive Performance, Training Load and Tethered Force During Tapering in Young Swimmers**

Douda, H.1, Toubekis, A.G.2, Gourgoulis, V.1, Thomaidis, S.1, Douda, H.1, Tokmakidis, S.P.1

1Democritus University of Thrace, Komotini, Greece, 2Kapodistrian University of Athens, Athens, Greece,

During a four-week training period closing with a two-week taper before a National competition (NC) the training load (TL) of twelve young swimmers (age: 14.2±1.3 yrs) was calculated by the product of the session-RPE score with the training duration. Tethered swimming force (TF), hand-grip strength (HG) and body fat (BF) evaluated 34, 20 and 6 days before the NC were unchanged (p>0.05). The TL differences of week 4 vs. week 1 before the NC was related to percent performance change (0.11±1.6%, p>0.05; r=0.63, p<0.05). The TF, HG and BF changes were not related to performance changes (p>0.05). The TL changes alone accounted for 40% (r²=0.4, SEE=1.37%, p<0.05) of the variation of percentage performance changes. The session-RPE training load calculation may be useful for effective taper planning.

**Key words: training load, tethered swimming force, arm strength**

**INTRODUCTION**

Intense training increases the training load and accumulates fatigue causing deterioration in several performance-related, physiological and psychometric parameters and may decrease competitive performance. In order to increase performance swimmers should follow a taper, which is a period of progressively reduced training load several days before an important competition (Bosquet et al., 2007). Swimming training during the taper period may be accompanied by positive changes of previously deteriorated psychometric, physiological, performance-related and neuromuscular parameters (Mujika et al., 1996; Hooper et al., 1999; Papotti et al., 2007). This is probably achieved by an appropriately planned maintenance of intensity and reduction of the training load which have an impact on performance (Mujika & Padilla, 2003). Although calculation of training load has difficulties and limitations, a simple method was recently suggested by Wallace et al. (2009). It is recommended that using a 10-point RPE scale, swimming coaches may estimate the training load of their swimmers. Although other psychometric variables have been evaluated during the taper period (Hooper et al., 1998), there are no reports for the use of the session-RPE method for the estimation of training load during a training period leading to a National championship. Furthermore, changes in other performance variables such as tethered swimming force (Hooper et al., 1998; Papotti et al., 2007) or arm-crank power have been related with swimming performance (Trinity et al., 2006). However, tethered swimming forces have been measured before competition simulation tests but not before official competitions (Hooper et al., 1998; Papotti et al., 2007). The purpose of the present study was to examine the effect of changes in session-RPE training load and tethered swimming force, the period before and during the taper for the National Championship.

**METHODS**

Twelve competitive swimmers (female, n=8, male, n=4; age: 14.2±1.3 yrs, body mass: 62.3±9 kg, height: 1.72±0.08 m) participated in the study. Each swimmer had qualified and participated in the National Championship (NC) competing in two or three races at various distances (i.e. 50 and 200 or 200 and 1500 m). Because of different race distances the average percentage performance change of all individual races was used in the analysis. None of the swimmers was a distance specialist. Five swimmers were specialized in breaststroke, six swimmers in front crawl
and backstroke events, and one swimmer in butterfly. All swimmers had followed regular training and competitive participation during the previous four to six years.

The swimmers’ training was recorded daily and the training load was calculated multiplying the 10-point rating of the perceived exertion scale (RPE) score with the training duration in minutes (Wallace et al., 2009). The training duration in minutes was recorded by the experimenters and the RPE scale was shown to each swimmer 30 minutes after the end of each training session. This time was selected to ensure the report of a global RPE for each session as has been suggested by Wallace et al., (2009). The daily load was summarized to a weekly training load. The weekly session-RPE load was calculated the four weeks before the NC (week 1: the last before NC). All swimmers were familiarised with the use of the RPE scale fifteen days before the examination period.

Thirty-four days (TEST 1), twenty days (TEST 2) and six days (TEST 3) before the NC each swimmer’s tethered swimming force during a 15 s maximum effort test, the hand-grip strength (HG) and the percentage of body fat (BF) were evaluated. Hand-Grip strength was selected because it has been shown to correlate with performance in young swimmers (Geladas et al., 2005), while BF may show body composition changes that have been reported during the taper period (Mujika et al., 2004). Tethered swimming force was measured using a piezoelectric force transducer interfaced to an analog to digital converter (Muscle-Lab, Ergometric). Swimmers were familiarized with the procedure a week before the first test and followed the same warm-up before each test. The procedure had previously been tested for its reliability (ICC=0.985; p<0.05). The best individual technique was used during testing (the butterfly specialist used front crawl) and all tests were performed at the same time of the day. The isometric hand-grip strength (Grip-D TKK S401 Takii Scientific instruments) was evaluated with the right and the left hand. The mean of two maximum efforts with 3 to 4 s duration for each hand was used for the analysis. Percentage of body fat was estimated from the skinfolds of triceps and mid-calf using the equation suggested by Slaughter et al. (1988). All procedures were approved by the departmental review board, and were explained to swimmers and their parents, who signed a consent form.

Backward multiple linear regression analysis was used to predict the percentage change of NC performance (dependent variable) using as independent variables the training load difference of week 4 minus week 1, tethered force (TF), hand-grip strength (HG) and body fat (BF) percentage changes between TEST 3 vs. TEST 1 and TEST 3 vs. TEST 2. No intervention was planned during the taper period and the coaches made their own decisions without any information concerning the results of each measurement. According to the coaches plan all swimmers started the taper period fifteen days before the commencement of the NC (week 2 and week 1).

One or two-way analysis of variance for repeated measures and the Tukey post-hoc test were used to examine differences between means. The Pearson correlation coefficient was used to test the relationship between variables. The data is presented as mean±SD and the level of significance was set at p<0.05.

RESULTS
Training distance was significantly reduced during week 1 (last week of taper), week 2 and 3 compared to week 4 and during the last week of taper compared to week 2 (Figure 1, p<0.05). The training load was reduced during week 3 and week 1 compared to week 4, but was increased during week 2 compared to week 3. The lowest training load was observed during the last week before the NC (Figure 1). Training load was decreased by 30±29% and training distance was reduced by 35±12% from week 4 to week 1.

Figure 1. The training load and distance changes during the four-week period preceding the National Competition (NC). Taper period was during W2 and W1. * p<0.05 vs. W4, # p<0.05 vs. W2. W4, W3, W2, W1: the week number before the NC.

Percentage change of performance during NC compared to the previous best performance (the starting list time of the NC) was not significant (0.11±1.6%, 95%CI: -0.9, 1.1%). The average competitive velocity of the starting list time compared to the velocity at the NC was no different (1.334 vs. 1.337 m·s⁻¹, p>0.05). Six swimmers improved by 1.3±1.3% while six swimmers showed decreased performance by 1.1±0.8%, however, these changes were not significant (p>0.05). In Figure 2 is shown the relationship between percentage change performance in the NC following the two-week taper and the session-RPE training load difference of week 4 minus week 1 (r<0.63, p<0.05).

Hand-grip strength, TF and BF did not change during the three testing periods (TEST 1, TEST 2, TEST 3) and their changes were not related to the percentage change of performance (TF: 112.38, 114±41, 115±41 N, HG-right arm: 35±11, 34±11, 34±12 kg; HG-left arm: 33±9, 32±8, 33±9 kg, BF: 20.1±6.3, 19.1±5.9, 19.5±5.9%, p<0.05). Tethered force during the 15 s test performed at TEST 1, TEST 2 and TEST 3 periods was reduced after 10 s independent of the testing period and no interaction was observed between tests (Figure 3). The fatigue index during the 15 s test was not different between testing periods (TEST 1: 17±8, TEST 2: 16±8, TEST 3: 20±10%, p>0.05). The percentage change of performance variation was predicted by changes in training load of week 4 minus week 1 (W4-W1), r²=0.40, multiple r=0.63, SEE=1.37%, p<0.05). The HG, TF and BF changes from TEST 1 to TEST 3 and from TEST 2 to TEST 3 were removed from the model as not significantly contributing to the prediction. The prediction equation is: percentage of performance change = 99.042+0.007*(training load of W4-W1).

Figure 2. The relationship of percentage change on performance with the training load difference of week 4 minus week 1. The discontinuous horizontal line separates swimmers who were improved (filled dots above the line) with those not improved (open dots below the line).

DISCUSSION
The most important finding of the study is the high relationship between the training load difference of week 4 and week 1 before the taper with percentage changes of performance time. The training load in the present study was calculated using the 10-point RPE scale. With this...
scale, swimmers expressed the general feeling of fatigue after training. It has been shown that significant improvement of psychometric parameters during a taper may be related to performance of swimmers (Hooper et al., 1999). It seems that calculation of training load with this method takes into account the “global” feeling of fatigue of the swimmers.

It has been shown that training load should be reduced more than 50% (Mujika and Padilla, 2003) and training distance by 41 to 60% for an effective taper (Bosquet et al., 2007). In the present study the taper planned by the coaches failed to meet these criteria since training load and distance were decreased only by 30% and 35% respectively from week 4 to the last week of taper. It should be noted that five of the six swimmers who improved their performance showed the greatest difference in training load between week 4 and week 1 (Figure 2). Although not significant, this 1.3% improvement in performance of six swimmers may be important for improving the placing in a race.

It is likely that the swimmers were not overloaded enough the weeks preceding the taper (weeks 3 and 4). In fact, the calculated training load was somewhat reduced during week 3 before a local competition. This occurred because the coaches decided to reduce the training distance of week 3 aiming to increase the number of individual qualifying events for the NC. Whatever the case, it has been reported that performance may improve more after taper with prior increased training overloading, than without prior overloading (Thomas et al., 2008). A likely less than necessary overload before the taper or the small percentage decrease of training load and distance from week 4 to week 1 before the NC may partly explain the failure to improve performance in this group of swimmers. It is also likely that given the absence of overload training before the taper, a shorter than fifteen days taper duration may be required for an effective performance outcome in this group of young swimmers.

The performance of NC was compared to the best performance of the year in the present study. Previous studies compared performance changes after a taper with performance after an intensified training period and this may have caused a greater reported percent improvement (Hooper et al., 1998; Papoti et al., 2007; Trinity et al., 2008). Furthermore, the swimmers participated in a local competition at the start of the taper after a reduction of training distance and load (Figure 1) and some of them achieved personal best performance time during this competition (after week 3). This may have decreased the chance for a further improvement of performance, since it was possibly difficult to achieve a better performance in the NC after the two weeks of tapering. Although the training distance and load reduction during week 3 was not characterised as a tapering, it cannot be overlooked that it may have had an impact on the following taper and subsequent NC performance. It has been shown that after reduction of training load for a conference competition, the performance achieved in a following taper is reduced (Trinity et al., 2008).

Changes in training load of week 4 and week 1 may be used to explain 40% of the variability of performance. Previous studies have reached high prediction values (r=0.98, Hooper et al., 1999) using a combination of physiological and psychological variables. Inclusion of physiological variables in combination to training load may increase the predictability in future studies.

Tethered force did not improve during the experimental period (p>0.05). Other studies have found improvement in mean tethered force measured during a 30 s test (3.8%) and peak force (11%) during 20 strokes of maximum intensity (Hooper et al., 1998; Papoti et al., 2007). In both studies the swimmers were tested after an intensified training period of four weeks and the force produced was compared to the force a day before the competition or two days later. In the present study no intensified training was followed before the taper and the swimmers were tested six days before the NC. Furthermore, different test duration (30 vs. 15 s) or different aspects of force (peak vs. mean force) were measured. Whatever the case, tethered swimming force in a 15 s test may not be sensitive enough to detect changes in performance after a taper. It is also likely that force changes had occurred during the last five days of the taper and were not detected by the present experimental design.

CONCLUSION
The use of performance–related tests may be useful for swimmers’ training evaluation but may not be sensitive enough to detect changes of training load and performance occurring before and during a taper. The use of session-RPE training load may be a useful and simple tool not only for the evaluation of training load but also for the improvement of taper planning.

REFERENCES
Perceived Exertion at Different Percents of The Critical Velocity in Front Crawl

Franken, M.1, Diefenthaeler, F.1,2, de Souza Castro, F.A.1
1Federal University of Rio Grande do Sul, Porto Alegre, Brazil. 2Federal University of Santa Catarina, Florianópolis, Brazil.

The aim of the present study was to compare and correlate the perceived exertion (PE) behaviour at different percents of the critical velocity (CV) in front crawl. Ten trained male swimmers (19.4 ± 2.2 years) performed five trials of 200 m at different percents of the CV (90, 95, 100, 103 and 105%), in random order, 90 s of passive rest. PE presented significant differences (p<0.05) among percents of the CV in front crawl. Significant correlation between PE with percents of the CV was observed (rho=0.785, p<0.01). Results suggest that PE increases as percent of the CV increase, but in a non-linear relationship.

Key-words: Perceived exertion, Critical velocity, Front-Crawl.

INTRODUCTION

Perceived exertion (PE) is a non-invasive and practical physiological parameter that shows a linear relationship with exercise intensity (Borg, 1982; Lima et al., 2006). Recent studies indicate that PE has an important role in exercise tolerance control during swimming (Suzuki et al., 2007). PE is understood as a complex, central, and integrated representation of acute physiological changes during exercise (Cafarelli, 1982; ST Clair Gibson et al., 2003; Albertus et al., 2005).

Critical velocity (CV) was primarily defined as the average speed of swimming for the concentration of 4 mmol·l⁻¹ blood lactate (Wakayoshi et al., 1992), but, most recently it was defined as the upper limit of the heavy intensity domain, i.e. the highest intensity that can be sustained for a long period of time not reaching maximal oxygen uptake (VO₂_MAX) at a constant workload (Dekerle et al., 2008). Increase in the blood lactate concentration ([La]), VO₂_MAX, PE, and heart rate (HR) have been observed during prolonged swim tests at an intensity similar to the CV (Ribeiro et al., 2010). However, Dekerle et al. (2009) observed an increase in PE but no difference for [La] during ten 400 m repetition, with 40 s rest, at swimming velocity corresponding to 100% of the CV.

The mechanism that explains PE behavior at severe intensities is associated with the anaerobic work capacity (AWC), defined as the maximum amount of work that can be produced from anaerobic energy systems (Monod & Scherrer, 1965). Thus, increased PE would be a response to the efferent neuromotor activity in order to compensate peripheral disturbances associated with phosphagen depletion and metabolic acidosis (Cafarelli, 1982; Suzuki et al., 2007). Lima et al. (2006) observed individual correlation (0.95 – 0.99) between PE and velocity during five trials of 200 m incremental repetitions based on PE. However, PE is influenced by other physiological changes and non physiological factors (i.e. duration and/or distance; Albertus et al., 2005). Thus, an incremental test based on PE could induce swimmers to increase velocity linearly.

To examine randomly the influence of different intensities in order to verify the real behavior of PE and avoid interference of situational factors is necessary. In swimming, there is a gap regarding studies comparing PE at different percents of the CV. Therefore, the purpose of this study was to compare and correlate PE behavior at different percents of the CV in front crawl.

METHODS

Subjects. Ten trained male swimmers (19.4 ± 2.2 years), with at least six years of competitive experience participated. All participants signed an Informed Consent Term to participate in the study, which was approved by the Committee of Ethics in Research with Humans of the institution where this study was conducted. Tests were conducted during training period. All subjects were asked to refrain from any high-intensity or exhaustive exercise at least 24 hours before the trials. The participants characteristics were (mena ± SD) for skinfold sum (tricep, abdominal, supraspinale, and subscapular) 46.1±10.8mm, stature (cm) 173.2±4.2, arm span (cm) 180.4±7.4, and body mass (kg) 64.7±7.1.

Borg scale familiarization. All participants performed five familiarization sessions with the Borg 15-point scale to be used in the next stage. Scale was presented during training at different intensities so that swimmers could attribute a numerical value in the corresponding scale to their PE at that moment. Scale presents verbal attributes next to the numbers to facilitate the selection. Participants would familiarize themselves with the use of the scale and memorize the relation between verbal attributes and the numerical values they should report (Borg, 2000; Nakamura et al., 2005).

Critical velocity determination. Protocol was performed in a 25 m indoor swimming pool (water temperature 28-30°C). After free warm up, the subjects swam, in an arbitrary order, with at least 24 hours of rest, two maximal repetitions (200 and 400 m). Two skilled appraisers using chronometers (Technos, model 100 lap memory, Suíça), with 0.01 s of resolution, registered the total time during both tests. Each distance was plotted as a function of the total time. By the slope of the distance-time relationship the angular coefficient, which represents CV, was calculated individually (Dekerle et al., 2009).

Test based on different percents of the CV. After 48 hours from last maximal repetition, the subjects performed five 200 m repetitions at different percents of the CV (90, 95, 100, 103 and 105%), in random order, with 90 s of passive rest, to obtain PE. Total time in each repetition (T₂₀₀) was computed and used later to calculate mean swimming velocity (SV). During repetitions SV was controlled by sonorous signals and visual gesticulation, for every single 25 m, in an attempt to minimize the difference between real time and prescribed time. An error of ± 2.5% was accepted for each trial (at each percent of the CV). At the end of each repetition the subjects attributed a numerical value in the corresponding Borg 15-point scale and received the T₂₀₀ in order to adjust their rhythm to the next repetition.

Statistical analysis. All the data were reported for median and/or mean and standard-deviation for PE and CV. Data normality was confirmed by Shapiro-Wilk’s test. Between real percents of the CV and PE values at each percentage of the CV was used Friedman’s test for non-parametric data. For main effects a Wilcoxon’s test was used. Correlations among variables were verified by Spearman’s correlation test for non-parametric data, and Student’s test was used to compare the different percents of the CV, prescribed CV, and real SV. When differences between prescribed CV and real SV were observed, the real SV was compared to the SV of the percent above. The statistical analyses were performed using SPSS 12.0 (SPSS Inc., USA). A significance level of 0.05 was adopted for all tests.

RESULTS

Table 1 shows mean values of maximal velocity at 200 m (V₂₀₀), maximal velocity at 400 m (V₄₀₀) and CV. Table 1: Mean and standard-deviation for performance at 200 m (V₂₀₀) and 400 m (V₄₀₀) and critical velocity (CV) (n = 10).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (m·s⁻¹)</th>
<th>SD (m·s⁻¹)</th>
<th>CV (m·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V₂₀₀</td>
<td>1.42</td>
<td>0.13</td>
<td>1.24</td>
</tr>
<tr>
<td>V₄₀₀</td>
<td>1.32</td>
<td>0.09</td>
<td>1.13</td>
</tr>
</tbody>
</table>

Table 2 presents a comparison between prescribed critical velocity (CVₚ) and real swimming velocity (SVₚ) and comparison of the percents where there occurred significant differences between CVₚ and SVₚ with the percent immediately above. Significant differences occurred in CVₚ at 90, 95 and 100% of the CV when compared with SVₚ and between percents immediately above, indicating that protocol used was valid.
DISCUSSION

Swimmers evaluated in the present study presented significant differences for PE in all percentage categories of the CV (p<0.05), demonstrating that PE increases as percent of the CV increases. Further, PE showed a significant correlation (rho=0.785) with percent of the CV (Figure 1). The results are in agreement with others studies that found a correlation between CV and PE during incremental swimming tests (Ueda and Kurokawa, 1995; Lima et al., 2006). Knowing that PE is associated with other parameters, Marriot and Lamb (1996) correlated PE with mean power (Watts) during an incremental rowing test and observed a linear correlation (r=0.96).

Lower correlation values observed between CV and PE in the present study compared to the literature could be explained by the PE role in exercise intensity tolerance control. It seems that PE does not necessarily increase when percent of the CV increases throughout short-duration interval training in swimming. PE behavior is explained by the AWC mechanism at severe intensities (Monod and Scherrer, 1965) and PE increases are led by efferent neuromotor signals sent to active muscles, including the space/time pattern of motion for technical gesture and extracellular control system for the control of the metabolic rate in muscle during exercise (Ulmer, 1996). Possibly, the workout duration chosen was not long enough to alter metabolic rate, resulting in a non-linear relationship between PE and different percents of the CV. Two limitations are identified: 1) although the order of the swim trials was randomized, 90 s of rest could have been insufficient for recovery after 105%, affecting the PE; 2) there was no control of the metabolic variables that could confirm the results of this study.

CONCLUSION

PE presented a significant correlation with percent of the CV, however it was non-linear. This suggested that PE does not always increase as percent of the CV increases during short bouts in front crawl. More studies are necessary to verify PE behavior at upper limits of the heavy intensity domain.

REFERENCES


ACKNOWLEDGEMENTS
The authors are grateful for Daniel Geremia and Caio Baganholo Contador and athletes; Grupo de Pesquisa em Esportes Aquáticos – GPEA; Grupo de Pesquisa em Biomecânica e Cinesiologia – GPBIC, Universidade Federal do Rio Grande do Sul (UFRGS).

Ventilatory and Biomechanical Responses in Short vs. Long Interval Training in Elite Long Distance Swimmers.

Hollard, P.1,4, Dekerle, J.2, Nesi, X.1, Toussaint, J.-F.1, Houel, N.1, Hausswirth, C.1
1Département recherche, Fédération Française de Natation, Paris France.
2Chelsea, School, University of Brighton, England.
3Département des Sciences du Sport, INSEP, Paris, France.
4Institut de recherche en médecine et en épidémiologie du sport, IRMES, Paris, France.

The objective of this study was to compare in seven elite male long-distance swimmers (Mean ± SD, age 21.4±3.5 yrs; weight 71±5 kg; height 180±5 cm), physiological responses (mean oxygen uptake (VO₂\text{mean}), carbon dioxide production (VO₂\text{CO2}), ventilation (VE\text{mean}), heart rate (HR\text{mean}), time sustained above 90% of VO₂\text{max} (T90%), blood lactate concentration (Bₜ), stroke rate (SF\text{mean}), and stroke length (SL\text{mean}) during two different interval training sets (6x500 m (IT6x500) and 30x100 (IT30x100)) performed in random order at the velocity at Lactate Threshold (vLT) with the same work-to-rest ratio (60 vs. 15 s). Compared with the IT6x500 set, the IT30x100 set displayed greater ventilatory responses but with shorter stroke length to maintain a given sub-maximal speed. Short-interval training can be used to develop the distance per stroke while long interval training allows training to prevent the deterioration of stroke mechanics during high oxygen consumption regimens.

Key words: Interval training, physiological responses, lactate threshold.

INTRODUCTION
The impact of a training set can be modulated by varying the duration, intensity, and the number of repetitions and rest periods between training intervals (Astrand et al., 1960; Bentley et al., 2005; Billat, 2001; Essen et al., 1977; MacDougall and Sale, 1981; Olbrecht et al., 1985). Changes in the parameters of a training set also has an effect on the amount of time the athlete trains at a given percent of VO₂ max and thus affects long-term physiological adaptations in long distance training (Astrand et al., 1960; Bentley et al., 2005; Billat, 2001; Essen et al., 1977; MacDougall and Sale, 1981; Olbrecht et al., 1985). Intermittent bouts with long intervals in-between, swim at velocities close to maximum lactate steady state (vMLSS) and VO₂max (v VO₂\text{max}) enables athletes to maintain higher speeds (Bentley et al., 2005; Billat, 2001; Essen et al., 1977; MacDougall and Sale, 1981; Olbrecht et al., 1985). This range of speeds is associated with preferential catabolism of lipid substrates via the attenuator effect of citrate produced by glycolysis during the intervals of rest (Essen et al., 1977). This leads to less pronounced serum lactate concentrations for equivalent or higher VO₂ than reached during continuous training performed at lower speeds (Billat, 2001; Olbrecht et al., 1985). Because of the short periods of recovery in-between repetitions, intermittent training also enables the restitution of myoglobin-bound oxygen stocks and higher muscular concentrations of adenosine triphosphate (ATP) and creatine phosphate (CP) so that during the first phase of a subsequent work, β-oxidation is favored over glycolysis. Lesser accumulation of lactate at a given VO₂ max appears to be even more attractive in swimming as the stroke efficiency seems to deteriorate passing the anaerobic threshold pace. This is thought to be a consequence of a greater local fatigue (Dekerle et al., 2005). Moreover, intermittent training would enable the swimmer to maintain speeds close to those of competition, which is useful for speed-specific neuromuscular and coordination adaptations (Billat, 2001; Essen, 1977; Olbrecht et al., 1985). It is hypothesized that in high-level long-distance
swimmers, very long training intervals (repetitions of 500 m) swum at lactate threshold would lead to greater oxygen uptake, higher stroke rate, and shorter stroke length than those observed during intervals of shorter distance (repetitions of 100 m).

METHODS

Seven long-distance male swimmers competing at the national and international level participated in this study.

Table 1. Individual anthropometric characteristics and training content.

<table>
<thead>
<tr>
<th>S</th>
<th>Age (Y)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>v LT- (km)</th>
<th>v LT+ (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>61</td>
<td>176</td>
<td>2100</td>
<td>380</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>74</td>
<td>188</td>
<td>1900</td>
<td>290</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>75</td>
<td>185</td>
<td>2050</td>
<td>370</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>69</td>
<td>175</td>
<td>2200</td>
<td>303</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>76</td>
<td>182</td>
<td>2200</td>
<td>320</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
<td>69</td>
<td>174</td>
<td>2350</td>
<td>352</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>76</td>
<td>182</td>
<td>2200</td>
<td>330</td>
</tr>
<tr>
<td>M</td>
<td>22</td>
<td>71</td>
<td>180</td>
<td>2143</td>
<td>335</td>
</tr>
<tr>
<td>SE</td>
<td>3.2</td>
<td>5.5</td>
<td>5.4</td>
<td>143</td>
<td>34</td>
</tr>
</tbody>
</table>

v LT- , annual training volume at low intensity below the lactate threshold. v LT+, annual training volume at high intensity above the lactate threshold.

All participants completed three experimental sessions in a 50-m open pool (26°C) during one week of standardized training. The first training test consisted in a progressive incremental test to exhaustion. The other tests were two randomized interval sessions – 6 x 500 m (IT6x500) or 30x100 m (IT30x100) – performed at the velocity corresponding to lactate threshold (vLT). During each interval session, the time spent at 90% above VO2max and 90% above maximal heart rate (HRmax) were determined retrospectively. The incremental test included five consecutive 300-m swims separated by 30s of rest. The speed of each increment was determined from the best performance of each swimmer in the 400-m freestyle event measured during the month preceding the test. The speed for the first 300-m was 30-s slower than the average 300-m pace over the 400-m best performance and this time was then reduced by increments of 5 s for each consecutive 300-m until the final 300-m at the swimmer’s fastest speed. Swimming speeds were monitored with Aquapacer ‘Solo’ (Challenge and Response, Inverurie, UK) so that each swimmer could match auditory signals with visual markers positioned every 12.5 m along the border of the pool. Blood lactate level (expressed in mM/L) was determined from a fingertip blood sample which was analyzed immediately using a portable lactate analyzer (Lactate Pro, Arkay, Japan). Breath-by-breath respiratory data were collected with a portable gas analyzer (Cosmed K4b2, Rome, Italy) connected to an Arkray, Japan). Breath samples were then averaged over 30 s and VO2peak and HRpeak were measured and expressed in % of VO2max. Serum lactate level was measured at the end of each IT session.

RESULTS

Stroke length was longer during IT6x500 than IT30x100 (2.45 ± 0.16 vs. 2.30 ± 0.16 m, P < 0.05) (Figure 1) and stroke rate tended to be lower (35.4 ± 3.3 vs. 37.8 ± 3.2, s·min⁻¹, P = 0.08).

There was no significant difference in swimming velocity between IT6x500 and IT30x100 for each 500 m. Expressed in % of VO2max and % of LT, swimming velocities were 96.4 ± 3.4 and 99.2 ± 3.6% for IT6x500, and 96.7 ± 3.4 and 99.4 ± 4.4% for IT30x100, respectively. Although the swimming velocity was similar during IT6x500 and IT30x100, VO2peak, VEpeak, BH, and RPE were greater for IT6x500 than IT30x100 (63.8±5.9 vs. 57.3±3.1 mL·kg⁻¹·min⁻¹; 79.6±18.8 vs. 73.2±10.5 mL·kg⁻¹·min⁻¹; 4.1±1.2 vs. 3.2±1.4 mmol·L⁻¹; 17.3±2.4 vs. 14.7±3.1 a.u; P < 0.05). T>90% was greater for IT6x500 (1357 ± 288 vs. 562 ± 326 s, P < 0.05) (Table 2).

DISCUSSION

The major finding of this study is that the long interval training set (IT6x500) which was performed at ≥LTL displayed higher physiological responses and longer time sustained above 90% VO2max compared with the shorter interval training (IT30x100). This is in agreement with the pioneer work on physiological response to interval training conducted by Astrand et al., (1960) who demonstrated that for exercise performed at 98% of the workload corresponding to VO2max, long interval exercise allowed athletes to attain VO2max whereas short-interval training led to sub-maximal response (63% VO2max). Conversely, our results are not in agreement with those reported by Bentley et al. (2005) who compared, in eight elite swimmers, two interval training sessions comprising 4 repetitions of 400m or 16 repetitions of 100m completed at a velocity representing 25% of the difference between ventilatory threshold and VO2max (Δ25%). They were unable to find any significant difference in the physiological responses. The apparent discordance with our data might be attributed to the shorter intervals (400 vs. 500 m), the smaller exercise volume (1600 vs. 3000 m).

For elite long-distance swimmers, training at ≥LTL over long intervals would probably be particularly useful as has already been reported
Table 2. Maximal and peak physiological variables obtained in the (ITE6x300) incremental test to exhaustion (ITE6x300-m) and mean physiological values obtained in the 30x100-m (IT 30x100) and 6x500-m (IT 6x500) IT sessions.

<table>
<thead>
<tr>
<th>Incremental test. Maximal values.</th>
<th>Interval training sets. Mean values.</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT 6x300</td>
<td>IT 30x100</td>
</tr>
<tr>
<td>V (m s⁻¹)</td>
<td>1.51 ± 0.02 1.46 ± 0.06 1.45 ± 0.06</td>
</tr>
<tr>
<td>% VO₂ max</td>
<td>100 96.7 ± 3.6 95.9 ± 3.2</td>
</tr>
<tr>
<td>VO₂ (mL·kg⁻¹·min⁻¹)</td>
<td>69.2 ± 6.5 57.3 ± 3.1* 63.8 ± 3.9</td>
</tr>
<tr>
<td>% VO₂ max</td>
<td>100 82.8 ± 3.7* 91.3 ± 3.6</td>
</tr>
<tr>
<td>VCO₂ (mL·kg⁻¹·min⁻¹)</td>
<td>62.1 ± 5.7 48.6 ± 6.3* 54.8 ± 2.4</td>
</tr>
<tr>
<td>% VCO₂ max</td>
<td>100 78.3 ± 7.7* 88.2 ± 9.7</td>
</tr>
<tr>
<td>VE (mL·kg⁻¹·min⁻¹)</td>
<td>1749 ± 166 1281 ± 193* 1392 ± 207</td>
</tr>
<tr>
<td>% VE max</td>
<td>100 73.2 ± 10.5* 79.6 ± 17.8</td>
</tr>
<tr>
<td>Lactate (mmol·L⁻¹)</td>
<td>6.9 ± 1.4 3.2 ± 1.4* 4.1 ± 1.2</td>
</tr>
<tr>
<td>RPE (a.u.)</td>
<td>18.4 ± 3.1 14.7 ± 3.1* 17.3 ± 2.4</td>
</tr>
<tr>
<td>QR</td>
<td>0.98 ± 0.09 0.86 ± 0.09 0.86 ± 0.09</td>
</tr>
<tr>
<td>%QR max</td>
<td>100 87.9 ± 9.1 87.9 ± 8.1</td>
</tr>
<tr>
<td>HR (b·min⁻¹)</td>
<td>196 ± 7.3 175 ± 9.8 180 ± 6.2</td>
</tr>
<tr>
<td>% HR max</td>
<td>100 89.3 ± 3.8 91.8 ± 3.6</td>
</tr>
</tbody>
</table>

for moderately to highly trained or even elite athletes (Billat, 2001). The use of continuous or long-interval training sessions when performed at intensities close to the lactate threshold has been suggested to be particularly good for reducing energy cost (Billat, 2001; Jones, 1998), for an enhancement of the capacity of maintaining a larger proportion of VO₂ max over long periods of time. Nevertheless, the results of the present study also suggest that interval training sessions similar to the IT₆x500 protocol could be useful for developing stroke length while completing a large volume of training without metabolic overload (Olbrecht et al., 1985). In agreement, MacDougall and Sale (1981) who demonstrated that 30-s exercise periods alternated with 30-s rest solicited the aerobic metabolism less than 2-3 min exercise periods which produced a higher level of hypoxia. During the short intervals, Medbo et al. (1992) found that a large quantity of oxygen was stored in muscle myoglobin during the rest periods (10% of maximal cumulative oxygen debt) minimizing depletion during the exercise time and thus sparing the glycolytic pathway during exercise. The fall in phosphocreatine during the course of the exercise would be followed by resynthesis during recovery leading to lesser accumulation of lactate in the muscles compared with continuous exercise. Lower levels of glycolysis in both motor and ventilatory muscles during IT₆x500 would probably contribute to the lesser muscle fatigue (MacDougall and Sale, 1981), enabling the athlete to maintain longer stroke lengths. It could be suggested that this would enhance, long term, motor efficiency, an essential factor of fast swimming performance (Dekerle et al., 2005).

CONCLUSION

To conclude, during long interval training performed at lactate threshold, elite swimmers exhibited large amplitude of the VO₂ slow component and an increase in the ventilatory response that is linked to an increase in stroke rate. Moreover, responses observed during the short-interval training (IT₃₀x₇₁₅ο) were characterized by a better technical efficiency accompanied with a lower ventilatory and metabolic stress. Short-interval training can be used to develop the distance per stroke while long interval training allows training against the deterioration of stroke mechanics during high oxygen consumption regimens.

REFERENCES


Talent Prognosis in Young Swimmers

Hohmann, A.¹, Seidel, I.²

¹Institute of Sport Science, University of Bayreuth, Bayreuth, Germany ²Karlsruhe Institute of Technology, Karlsruhe, Germany

In talent selection a high level of competitive performance, and also of performance prerequisites are of interest. Furthermore, the trainability and utilization of the performance prerequisites, and also psychological factors have to be included. As the different components of the early talent make-up not only change over time, but also mutually suppress or enhance each other, talent development is a complex non-linear process. Linear models like discriminate analysis can only predict the talent development within a small range of the future performance outcome. Therefore, non-linear neural network methods turned out to be appropriate tools for talent detection purposes. By recognizing distinct patterns in the individual dispositions, the Self-organizing Kohonen Feature Map allowed for better predictions of the future success of talented swimmers.

Key words: Talent prognosis, swimming, discriminate analyses, neural network

INTRODUCTION

Recent theoretical contributions to the theory of talent in sport have clearly shown that a complex and longitudinal framework is necessary to successfully address talent identification and the talent promotion issue in most sports (Gagné, 1985; Abbot & Collins, 2002; 2004). Consequently, the early diagnosis of juvenile competition performances and performance prerequisites has to be complemented by a final follow-up search for the individual best performance of each adult athlete at the end of his/her career (Willimczik, 1982; Schneider, et al., 1993).

As talent development is a complex non-linear process, and the different components of early talent make-up not only change over time, but also mutually suppress or enhance each other, linear models like discriminate analysis can only approximate the non-linear talent development within a very small range of the future performance output. Because of this, neural networks also seem to be appropriate tools for talent detection purposes (Philippaerts, et al., 2008). Due to their pattern detection ability, such methods as e.g. the Self-organizing Kohonen Feature Map may allow to predict the future success of talents by revealing distinct patterns in the individual sets of sport specific dispositions.

The purpose of this paper is to compare the quality of linear and non-linear talent predictions, which are both based on prognostic valid talent criteria in swimming. Specifically, it shall be demonstrated that the talent development outcome can be better modeled by means of the non-linear Self-organizing Kohonen Feature Map (SOFM) network.

METHODS

The Magdeburg Talent study on Elite Sport Schools (MATASS; Hohmann, 2009) is a six year longitudinal study on the development of talented children and adolescents. It was conducted at the two Elite Sport Schools in Magdeburg, Germany, and was based on a sequential sliding populations design (Regnier, et al., 1993) with three test waves in the years 1997, 1999 and 2001. In each test wave all pupils of the swimming classes 5 to 12 were included. They were added by pre-selected young athletes from class 4 of the elementary schools and the graduates of the last year before the tests (see Fig. 1)

**Figure 1. The longitudinal study design of the MATASS**

The data for these analyses of swimming were collected from 1997 to 2001 from a total of N = 290 male (n = 172, Min = 128 months, Max = 276 months, M = 171.24 months, SD = 42.52) and female swimmers (n = 118, Min = 116 months, Max = 282 months, M = 159.25 months, SD = 39.02). The final competition performance data was recorded in the year 2006 for all male swimmers (n = 130, M = 234.51 months, SD = 37.99) and female swimmers (n = 113, M = 236.47 months, SD = 36.29) that were at least 16 years old. Thus, the diagnosis of the adult competition results took place about seven years after their personal best test results (males: M = 81.67 months, SD = 19.68; females: M = 76.98 months, SD = 17.95).

Twenty one physical and technical performance components of the swimming performance were measured. Elementary speed: (1) Reactive fall into the wall (wall contact time), (2) Reactive drop jump (ground contact time), (3) Foot tapping speed, (4) Accoustic reaction time, (5) Arm cranking speed. Complex speed: (6) Isokinetic arm pull (speed level 1), (7) Isokinetic arm pull (speed level 9), (8) Maximum rate of force development (isokinetic arm pull, level 1), (9) Standing high jump, (10) Standing long jump, (11) 7.5-m-start (into the water), (12) 5-m-flying sprint (in the water). Technique and coordination: (13) Crawl swimming technique, (14) Complex coordination (swimming with obstacles in the water), (15) Maximum pulling frequency (in the water). Strength: (16) Isometric maximum strength of the arms (bench press), (17) Maximum rate of force development of the arms (bench press). Anthropometric variables (body structure): (18) Arm span width, (19) Hand size, (20) Shoulder flexibility, (21) Broca index.

These variables were complemented by four psychological (achievement motivation, volition, stress stability, concentration) and four sociological (school support, family support, training environment, training load) performance components, which were collected via questionnaire. The best competition performance of each athlete in each of the three survey periods (1997, 1999, 2001) was also assessed. Finally, at the end of the study in the year 2006, the adult (peak) performance up to then of all athletes aged 16 years and older was recorded.

In a first step, the 21 physical and technical performance components were analysed by factor analysis (SPSS 14.0, SPSS Inc., Chicago, Ill.). Using this procedure, six complex and one-dimensional performance prerequisites were extracted by orthogonal factor analysis. In swimming, these factors were (1) body structure, (2) maximum strength, (3) general and (4) swim specific speed strength, (5) technique and coordination, and (6) elementary speed (Hohmann, 1999).

In a second step, the (1) juvenile competition performance and (2) the factor values of the six complex performance prerequisites served as well as talent predictors as the (3) speed of performance development, (4) speed of development of the performance prerequisites, (5) utilization (Kupper, 1980; Hohmann & Seidel, 2003), and (6) psychological stress stability. This set of six complex predictors was included in the talent prediction model that was used to determine the final tal-
ent outcome at the adult age of the participants. To define a criterion variable, all athletes were categorized into three different talent groups according to their personal best adult competition performance up to the year 2006. So, the best adult swimmers taking part in international championships were assigned to the category of extremely high talented athletes, the national calibre athletes were assigned to the category of highly talented swimmers, and the regional starters were labelled as normal talents.

In a third step, the six juvenile talent criteria described above (of the earlier time period 1997-2001) were used to predict the three final adult talent groups (of the year 2006). For the prediction of the final adult talent group two methods were used: firstly, a discriminate analysis (DA), and secondly, the neural network of a Self-organizing Kohonen Feature Map (SOFM; DataEngine, MIT Inc., Aachen, Germany).

To obtain a “true” prognosis, the talent forecasts on the basis of the discriminate analyses and on the basis of the neural network method have to follow a cross-validation procedure. In the case of the discriminate analyses, 50 percent of the total number of cases was used to compute the discriminate functions that were then used to determine the talent outcome of the remaining 50 percent of cases.

In the two specific SOFM models for the male and the female swimmers, the talent forecasts were validated by the “leave-one-out”-procedure. Therefore, one less than the total number of the data sets of the talents (n−1) were used to train the network (consisting of a 5×5 neuron layer) with 5 000 training steps. The remaining data set of the one single athlete was then presented to the neural network to calculate a prognosis of his personal adult peak performance category. After that, the predicted future talent category was compared with the real, already known adult performance category. This procedure was repeated for each single data set, so that the total number of correctly predicted cases represents the quality of the talent prediction models for the male and the female swimmers.

RESULTS

For talent identification purposes it is essential to know the early performance prerequisites that form the structure of the current, and also the future adult peak performance (e.g. for the female swimmers see Fig. 2).

Figure 2. Path analysis on the prognostic relevance of different performance prerequisites of young female swimmers for the future competition performance in 50 m sprint swimming (Hohmann, 2009).

The comparison of the real adult performance groups with the predicted future groups of the talented swimmers at adult age led to far better predictions, when the neural network method was applied. The percentages of correctly predicted cases by discriminate analysis (females: 69.0 percent; males: 50.0 percent) are much lower than those delivered by SOFM (females: 87.9 percent; males: 68.3 percent; Fig. 3).

Figure 3. Results of the talent prognosis in female (left) and male (right) swimmers on the basis of the nonlinear model of the Self-organizing Kohonen Feature Map (single and double arrows symbolize light resp. severe classification errors). Extreme talents: Participants in Olympic Games, World Championships, European Championships, and German Championship finals. High talents: European Youth Championships. Normal talents: German Youth Championships

DISCUSSION

This paper aimed at finding out whether the talent development outcome can be better modeled by means of the nonlinear mathematical method of artificial neural networks or by linear methods such as discriminate analyses. The percentages of correctly modeled performances in the linear discriminate analysis were comparably lower than in the non-linear neural network procedure. Thus, the results support the assumption of Philippaerts et al. (2008) that neural networks are excellent tools to model and to predict future competitive performance categories on the basis of juvenile talent make-up data.

Since there is no guarantee that such modeling and talent prediction will lead to similar results in other groups, the validation procedure has to be applied to data sets of other swimmers. Based on the results of this procedure it must be decided whether the neural network is a good or poor model of talent development in swimming. To obtain a good model, it may require changes in some of the training parameters.

CONCLUSION

The better results of the neural network analysis compared with the poorer results of the discriminate analysis support the interpretation that the adaptive behaviour of the athlete is a non-linear complex problem. This supports a dynamic systems approach to talent development in which the young athlete unfolds a performance development process in a self-organized way, which is influenced by various personal and contextual moderator variables (Gagné, 1985; Heller & Han, 1986; Heller, et al., 2005; Cote, et al., 2003).

As neural networks are able to recognize global patterns of different talent make-ups, they are a worthwhile tool in the detection of talents under the condition of the non-linear talent development. Hence, from a dynamical systems point of view, a successful neural network modeling may be interpreted as a representation of deviations of the different states of the system from equi-probability, in our case the identification of different patterns of juvenile athletic performance. This is a very interesting aspect of the modeling of competitive performances, because the non-linear dynamic systems perspective is rapidly emerging as one of the dominant meta-theories in the natural sciences, and there is also reason to believe that in the future it will eventually provide a more general integrative understanding in training science, as well.

REFERENCES


Determination of Lactate Threshold with Four Different Analysis Techniques for Pool Testing in Swimmers

Keskinen, K.L.1,2, Keskinen, O.P., Pöyhönen, T.3

1Finnish Society of Sport Sciences, Helsinki, Finland, 2Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland, 3Kymenlaakso Central Hospital, Kotka, Finland

Pool testing using the blood lactate versus swimming velocity relationship is a standard in performance diagnostics of swimmers. The reliability of four techniques designed to determine the lactate threshold (LT) were examined. The subjects were 15 female and 15 male swimmers. Mean ± SD for age was 16.7 ± 3.3 years, stature 1.70 ± 0.08 m and body mass 61.8 ± 6.6 kg. They performed a set of ten 100 meter swims twice in three days. LT was analyzed from the blood lactate - velocity association by two experienced analysts. Linear regressions (R²), intraclass correlation coefficients (ICC) with two-way ANOVA, and t-tests showed that both test-retest reliability and comparability between mathematical curve fitting and visual linear estimation methods were very high (R² = 0.85-0.96; ICC = 0.96-0.99; t-tests = N.S.).

Key words: pool testing, analysis techniques, reliability

INTRODUCTION

Blood lactate concentration (BLA) is one of the most commonly measured parameters in both clinical exercise testing and during performance testing of athletes. In healthy subjects a normal physiological response to physical strain is an elevated BLA. In response to progressive incremental exercise BLA-testing offers a convenient tool to observe its systematic behavior dependent on the intensity of exercise. Under low work rates BLA either remains at its initial lowest concentration or slowly increases. As the exercise becomes more intense, the BLA eventually increases exponentially. This is recognized as the lactate threshold (LT) (Stegmann et al. 1981). As a single work rate, illustrating the curvilinear BLA versus exercise intensity response, determination of LT is a standard procedure in both predicting athletic performances as well as in diseased conditions (Goodwin et al., 2007).

Even though the status of the LT as a powerful predictor of performance is well accepted the velocity at which LT appears depends on the pool test protocol applied. Keskinen et al. (1987) found that LT was different between 2:400 (Mader et al., 1978), n = 100 (Gullstrand et Holmer, 1980) and n = 300 m (Simon et al., 1982) swimming tests with different BLA values in each case. Evidently there is also a different reference point for LT when the definition is made using a frequently used n = 200-m protocol (Pyne et al., 1992).

In addition to different testing protocols, different analysis techniques have also been used. Mader et al. (1978) defined LT as a swimming velocity corresponding to fixed 4 mmol/l in BLA (V4) from a two-speed test. Due to its feasibility this test has since served as the reference for LT in several instances (Svedahl & MacIntosh, 2003).

In a practical sense, the BLA-velocity association has traditionally been plotted and the LT visually determined as the origin of the exponential increment. The concept of an individual LT was presented by Stegmann et al. (1981) with an incremental field protocol. Cheng et al. (1992) proposed a mathematical procedure to determine ventilatory threshold and LT as an objective and reliable method for threshold determination, which can be applied to various ventilatory or metabolic variables.

There is only limited information available in the scientific literature about the comparability and repeatability of the methods used...
for determination of LT. This study was thus designed to test whether commonly used analysis techniques were reliable in both test-retest and analysis-to-analysis comparisons.

**METHODS**

A total of 30 swimmers, female (n=15) and male (n=15) volunteered and gave their consent to serve as subjects (Table 1). Each subject performed a standardized pool test of ten 100 meter swims twice in a three-day period (Gullstrand & Holmer, 1980). Pace-lights were placed linearly along on the bottom of a 50 meter pool for visually adjusting swimming velocity. The initial velocity of the exercise was 0.45 m·s⁻¹ less than the individual maximum velocity. Velocity was increased by 0.05 m·s⁻¹ with each 100 meter swim until the test ended in exhaustion. The rest interval between the 100 meter swims was 90 seconds. Time for the 100 meter swims, as well as for 50 meter laps were taken by hand held watches to calculate mean velocity. Blood samples (20µl) were taken from the ear lobe immediately after each swim to obtain BLa (Boehringer-Mannheim).

Table 1. Physical characteristics of the subjects (mean ± standard deviation).

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Stature (m)</th>
<th>Body mass (kg)</th>
<th>BMI (kg/m²)</th>
<th>T100* (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pooled (n=30)</td>
<td>16.7 ± 3.3</td>
<td>1.70 ± 0.08</td>
<td>61.8 ± 6.6</td>
<td>21.3 ± 1.1</td>
<td>65.2 ± 5.7</td>
</tr>
<tr>
<td>Females (n=15)</td>
<td>17.3 ± 3.7</td>
<td>1.68 ± 0.06</td>
<td>60.7 ± 5.9</td>
<td>21.5 ± 1.0</td>
<td>67.3 ± 4.2</td>
</tr>
<tr>
<td>Males (n=15)</td>
<td>16.0 ± 2.7</td>
<td>1.72 ± 0.09</td>
<td>62.8 ± 7.1</td>
<td>21.2 ± 1.1</td>
<td>62.8 ± 6.3</td>
</tr>
</tbody>
</table>

*Time for best personal performance in 100 meter freestyle swimming

Two experienced analysts were used to define the LT from each test. The results from the analyses were compared between the two analysts. The BLa-velocity graphs were plotted, and subsequently the four different approaches were applied to define the LT. Figure 1 shows an example on how the determination was performed using the mathematical technique presented by Cheng et al. (1992). First the BLa-velocity plots were fitted with a 3rd power polynomial. Then the two ends of the polynomial were interpolated with a straight line. Finally, the point of maximal distance (Dmax) between the straight line perpendiculars to the polynomial was calculated. The velocity corresponding to the Dmax was used as the LT. The linear estimation model was used to detect individual LT so that two linear lines were formed. The first line was parallel to the x-axis connecting the BLa-velocity plots at low intensities without significant increase in BLa. The second line was drawn between the rapidly increasing BLa values in the latter part of the exercise neglecting those values at around the exponential phase of increasing BLa-velocity association. LT was defined as the velocity corresponding to the intersection of the two lines. Third analysis mode was the V4 as described earlier by Mader et al. (1978). Fourth analysis was the V corresponding to a 1 mmol·l⁻¹ increase in BLa above the lowest level (VΔ) during the exercise.

The mean (± SD) are presented as descriptive statistics. Coefficients and equations of linear regression were calculated between the parameters. Intraclass correlation coefficients (ICC) were calculated in connection with two-way ANOVA to indicate the test-retest reliability. T-test between paired observations was used to test the statistical significance of differences (p < 0.05).

![Figure 1](image1.png)

**RESULTS**

Test-retest comparison between the measured velocity in the two test sessions demonstrated a very high repeatability (y = 1.0023x + 0.0035, R² 0.994) being near to equal between the two sessions. Test-retest reliability for BLa was also very high (y = 0.9913x + 0.1365, R² 0.909). The swimmers’ ability to follow the pace-lights were very high (y = 0.9603x + 0.0519, R² 0.987). Inter-rater reliability was very high in three of the four analyses (Dmax, V4 and VΔ) where the LT was detected automatically. Linear estimation technique repeated the LT values with >99% accuracy. Thus, mean values were calculated only for the linear estimation method.

Table 2. The associations between the analysis methods (slope, intercept, R²).

<table>
<thead>
<tr>
<th></th>
<th>Slope</th>
<th>Intercept</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dmax and linear estimation</td>
<td>0.9902</td>
<td>+ 0.0153</td>
<td>0.928***</td>
</tr>
<tr>
<td>Dmax and V4</td>
<td>0.7094</td>
<td>+ 0.4005</td>
<td>0.802***</td>
</tr>
<tr>
<td>Dmax and VΔ</td>
<td>0.6632</td>
<td>+ 0.3832</td>
<td>0.712***</td>
</tr>
<tr>
<td>V4 and linear estimation</td>
<td>1.1396</td>
<td>- 0.2012</td>
<td>0.771***</td>
</tr>
<tr>
<td>VΔ and VΔ</td>
<td>0.9129</td>
<td>+ 0.0381</td>
<td>0.847***</td>
</tr>
<tr>
<td>VΔ and linear estimation</td>
<td>1.1654</td>
<td>- 0.1444</td>
<td>0.794***</td>
</tr>
</tbody>
</table>

*** p<0.001

![Figure 2](image2.png)
The present study was designed to test whether the four analysis techniques would show reliable measurement. As shown by Pyne et al. (2001), standardized blood lactate testing can be used successfully in monitoring changes in swimming performance over a training year. The strength of our study was that the swimming velocity was accurately controlled with pace-lights. In turning the swimmers were advised to regulate their speed during the push-off from the turning wall.

The second requirement for reliable testing is that the test results can be analyzed objectively. Our two experienced analysts showed identical results in three out of four methods (\(D_{\text{max}}, V_4\) and \(V_4\) - \(V_{300}\)), which constitutes the reliability of these investigations. Linear estimation which required visual inspection and a subjective decision, revealed a smaller degree of reliability although the reliability still was significant and very high. It is therefore suggested that mathematical handling of the analysis should be preferred to keep subjective influence to a minimum. The analysis method suggested by Cheng et al. (1992) seems to be the method of choice when determining LT from the \(BLA\)-velocity association.

Finally, for the test to be applicable to regular training practice it must also be valid. Previously Keskinen et al. (1987) observed that the n·100 meter test (Gullstrand & Holmer, 1980) could be compared to both the n·300 meter (Simon et al. 1982) and the 2·400 meter test (Mader et al., 1978). Keskinen et al. (1987) found that when compared with the \(V_{300}\) of the 2·400 meter test the same velocity in the n·100 meter test was found at 0.5 mmol\(\text{l}^{-1}\) increase in blood lactate above the initial lowest level. Similar velocity was found in the n·300 meter test at 1.5 mmol\(\text{l}^{-1}\) increase in blood lactate above the basic level.

The present results showed that the LT as analyzed by both \(D_{\text{max}}\) and linear estimation techniques corresponded well between each other, but there were significant differences to both \(V_4\) and \(V_{300}\). Conclusively, even though the determination of LT can be done similarly in various testing protocols, each protocol has its own distinctive to be taken into account. Cautiousness must therefore be practiced when exercise prescription is applied to athletes. Both over- and under-estimation of training speeds may deteriorate balanced development of the athlete.

CONCLUSIONS

It is concluded that the test-retest reliability of the n·100 meter swimming test was high indicating that the method itself was repeatable and is a useful means of monitoring changes in indicators of physical fitness in swimming. Also, the analyses offer reliable results which can be used for prescription of training. From the analysis-to-analysis comparisons the necessity to understand their specific characters must be emphasized. The original speed at which the LT appear depends specifically on the protocol being used.

REFERENCES


ACKNOWLEDGEMENTS

We greatly acknowledge the swimmers and coaches who participated in performing this study. We also want to thank the parents of the swimmers who gave their support to the research team. The personnel of the Aalto Alvari Swimming facility provided proper work conditions to run the experiments.
Competitive Systematization in Age-group Swimming: An Evaluation of Performances, Maturational Considerations, and International Paradigms

Kojima, K.¹ and Stager, J.M.¹

¹Indiana University, USA

The most appropriate method for grouping youth swimmers to assure fair competition has been debated for decades with little progress being made. The present study evaluates the age classification utilized at the 2nd FINA World Youth Swimming Championships and those used by swimming federations around the world. Our results illustrate a greater proportion of older participants and older finalists at the international event. No universal age-grouping system is evident among the various swimming federations. We conclude that most age-grouping systems, particularly those using a multi-age group paradigm, unduly influence participation and bias competition outcomes. More effective age-groupings are hypothesized. From these research findings, continued international discussion on this topic appears to be warranted.

Key words: youth swimming, age classification, growth and maturation, fairness in competition

INTRODUCTION

Competitive youth swimmers are commonly separated by sex and then stratified into competitive groups based on chronological age (CA). This is done regardless of the differences in maturational timing and tempo or physical size among the swimmers that may exist within a given CA (Malina et al., 2004). Implementing maturation- or size-based assessments for a more fair grouping system is not logistically practicable. Such assessments are complex, costly, invasive, potentially unsafe, and at times, unreliable. However, given the variation in maturity status within a single CA, collapsing CAs into multi-age categories does not assure competitive fairness and equity. Kojima et al. (2009) demonstrated the age-related differences in swim performance of the top 100 U.S. swimmers and confirmed the hypothesis that younger swimmers within the standard multi-age-groups used by USA Swimming are competitively disadvantaged. Whether or not this is true at the international level of competition remains to be determined.

With the intention of providing future World and Olympic level athletes with greater competitive and more intercultural experiences, the Fédération Internationale de Natation (FINA) hosted the second edition of the FINA World Youth Swimming Championships in July, 2008. Only one age-group was provided for each sex, combining 14-17 year-old girls and 15-18 year-old boys at the Youth Championships. However, considering the magnitude of our recent findings (Kojima et al., 2009), it was hypothesized that older swimmers within the multi-age-groups might represent the majority (or at least a greater proportion) of the finalists at this event. Furthermore, the age-grouping system that combined four CAs into a single group is likely to have resulted in age-related (also potentially maturation-based) competitive outcomes which might differ in the girls as compared to the boys. The goals of this study were 1) to evaluate the appropriateness of the age-groups at the 2nd FINA World Youth Swimming Championships and 2) to discuss age-grouping systems used by countries in the world as a means of gaining a better insight into the most appropriate age-group stratification paradigm.

METHODS

The 2nd FINA World Youth Swimming Championships: All data (i.e., meet results) were acquired from the official website of FINA (www.fina.org). The single age-grouping for each sex was composed of four CAs (ages 14-17 years for girls and ages 15-18 for boys). The Championships included 17 individual events for both sexes: 50-, 100-, 200-, 400-, 800-, and 1500-m freestyle, 50-, 100-, and 200-m backstroke, breaststroke, and butterfly, and 200- and 400-m individual medley. In addition, there were three relays: 400- and 800-m freestyle relays and 400-m medley relay. To investigate the influence of the age-groupings on the swimmers qualifying for preliminaries and finals, a frequency distribution of all competitors and the top 8 finishers in the 17 events was examined for each of the four CAs. A relative frequency distribution of all competitors and finalists was calculated and averaged over the 17 events. To examine the influence of the age-groupings on ‘chance of participation’ in the Youth Championships and selection at the trials of each country, the relative frequency distribution of relay members of the top 8 countries was examined. All data were analyzed using PASW Statistics 17.0 (SPSS inc., Chicago, Illinois). Chi-square tests were performed to determine whether or not there was a significant difference between the expected frequencies (a quarter of the total frequency for age) and the observed frequencies within the age-groups. One-way analysis of variance (ANOVA) with Tukey’s post-hoc test and Pearson product moment correlation coefficients were also used to test the research hypotheses. The level of significance was set at p < 0.05.

International age-grouping systems: Information regarding age-grouping systems of FINA swimming federations was collected from the website of each national federation. The following countries were selected for this study due to the lack of a common language: Australia, Britain, Canada, China (Hong Kong & Macau), Germany, Japan, New Zealand, Spain, Taiwan, and the USA. Phone correspondence was also made to obtain more details of each federation’s rationale and intent in their age-grouping systems.

RESULTS

The 2nd FINA World Youth Swimming Championships: The total number of swimmers in the 17 individual events was 754 for the girls and 943 for the boys. When expressed by age categories, in girls there were 66 swims (8.8%) by fourteen year-olds, 148 (19.6%) by fifteen year-olds, 218 (28.9%) by sixteen year-olds, and 322 (42.7%) by seventeen year-olds. In boys, there were 46 swims (4.9%) by fourteen year-olds, 148 (19.6%) by fifteen year-olds, 218 (28.9%) by sixteen year-olds, and 486 (61.5%) by eighteen year-olds. A significant difference was found between the observed and expected values in both sexes, indicating an uneven distribution of swims across age categories.

Figures 1 and 2 illustrate the relative frequency distributions (%) of the top 8 swimmers over the 17 events and relay members of the top 8 countries. Significant differences in the mean relative frequency among CAs were found in both sexes (Table 1). The oldest CA in both sexes (age 17 for girls and age 18 for boys) had a significantly greater proportion compared with all other age categories. The younger CAs had fewer swims in the finals and represented a smaller proportion of the total distribution. The age-related differences were more evident in boys. There was only one 15-year-old finalist (100-m butterfly) in boys, and he was the only swimmer under the age of 17 who competed in a relay final.
To investigate the chance to advance to the finals and therefore to score, i.e., chance of success, for swimmers in each CA category, the ratio of the number of top 8 swimmers to total competitors in each event was examined (Table 2). No significant difference in the mean ratio for the 17 individual events among CAs was found in girls, while the mean ratio in boys was significantly different (p < 0.01) and related to age (r = 0.59, p < 0.01). Table 2. The mean ratio of the number of finalists to the total competitors over 17 events by age category.

Table 1. Mean relative frequency distributions (%) of the top 8 swimmers and the top 8 relay members over all events for the four age categories.

<table>
<thead>
<tr>
<th></th>
<th>Girls</th>
<th>Boys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>IE finalists</td>
<td>Relay members</td>
</tr>
<tr>
<td>14</td>
<td>0.21 ± 0.10</td>
<td>0.20 ± 0.06</td>
</tr>
<tr>
<td>15</td>
<td>0.21 ± 0.14</td>
<td>0.16 ± 0.07</td>
</tr>
<tr>
<td>16</td>
<td>0.11 ± 0.11</td>
<td>0.08 ± 0.11</td>
</tr>
<tr>
<td>17</td>
<td>0.16 ± 0.18</td>
<td>0.03 ± 0.12</td>
</tr>
</tbody>
</table>

† Significantly different from the two youngest age categories (p < 0.05)
‡ Significantly different from the youngest and oldest age categories (p < 0.05)
¶ Significantly different from the youngest and oldest age categories (p < 0.05)

DISCUSSION

The hypothesis that older swimmers within the designated age-groups represent the majority of swims in the finals and that of competition at large was supported by the analyses. There were a greater number of older participants and finalists in both sexes. Furthermore, the odds of advancing to the finals for boys were significantly greater for the oldest swimmers at the Championships. By combining four ages into a single competitive cohort, participation was influenced and thus performance outcomes at the FINA Youth Championships were nearly predetermined. Although “fairness” was not a goal at this international event, the age-grouping system employed did not provide the younger swimmers within age-groups with an equal chance of experiencing a higher level of competition or any competitive success.

Age-related variations in physiological parameters related to sports performance during adolescence are well documented (Malina et al., 2004). These variations are attributable mainly to maturity status and size differences (e.g., limb length, height, and muscle mass) and become more apparent during and after the growth spurt, especially in boys. One marker of maturation is the age at peak height velocity (PHV; on average, age 12 in girls and age 14 in boys). Regarding swim performance data, Pelayo et al. (1997) reported age-related differences in the performance of non-skilled students aged 11 to 17 years. Also, Kojima et al. (2009) recently demonstrated age-related differences in the swim times of the top 100 U.S. swimmers from age 5 to 20 years. Both studies found significant differences in swim performance between 14- and 17-year-old girls, while swim performance of boys in 15 to 17 year-old categories was significantly different from each other. In each case, younger swimmers were slower than older swimmers. Girls reach a point where age (and maturity) is less of an issue about two years earlier than boys.

In the present study, younger swimmers typically placed lower than older swimmers (Figure 1). Nine 14 and 15 year-old girls (out of 51,
17%) finished within the top 3 in any of the 17 events. In the boys, no 15 or 16-year-olds finished in the top 3, and only ten 16-year-olds finished in the 4-8th places. There was only one 15-year-old finalist, and he finished 8th in this event. This might lead to the conclusion that age (and thus maturation) might be more important among boys than among girls, at least in this age range.

Within the relays, the majority of the finalists (81.2% in girls and 99.0% and in boys) were swimmers in the two oldest age categories (Figure 2 and Table 1). Moreover, the mean ratio of chance to advance to the finals over 17 events is presented by age categories in Table 2 (note that the ratio does not reflect the absolute number of swimmers, rather, swims). Significant differences in the ratios among CAs were revealed in the boys, while there was no significant difference in girls. This indicated that the age-grouping systems combining plural ages together would clearly influence competition and the chance of success, especially in boys due in part to their greatly varied maturational nature among these CAs. The data pertaining to the girls (similar ratios) imply that the difference in the number of finalists among CAs might possibly be reduced if the number of participants at each CA was equal.

**International age-grouping systems:** According to FINA, each national federation is allowed to adopt their own competitive age-groupings. Thus, there are a wide variety of age-grouping systems in swimming currently in use around the world (Table 3). Each of the ten countries examined in this study uses a different system to classify swimmers, from as few as four to as many as eight age-groups. Some federations adopt sex-specific age-groups where CAs in the girls are pooled in a different manner from the boys. Others provide the same age-groups for both sexes. Britain and Japan use single-age-based qualification times for national youth championships, although some age categories are combined into competitive groups for the actual competition. China and USA entrust age-grouping systems and rules to each provincial swimming association or local swimming committee, so there may not be a common age-grouping system across these countries.

Table 3. Age-grouping systems in representative swimming countries (federations).

<table>
<thead>
<tr>
<th>Country</th>
<th>Sex</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Unisex</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Britain</td>
<td>Male</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Canada</td>
<td>Male</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>China*</td>
<td>Unisex</td>
<td>Σ</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>France</td>
<td>Unisex</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Germany</td>
<td>Male</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Japan</td>
<td>Unisex</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Korea</td>
<td>Unisex</td>
<td>Σ</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Unisex</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Spain</td>
<td>Male</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Taiwan</td>
<td>Unisex</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>USA*</td>
<td>Unisex</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Unisex, the same age-groups are adopted for girls and boys; QT, qualification time for national or state youth (age-group) championships; Σ, total age-groups; *Age-grouping systems differ among local swimming committees or provincial swimming associations.

The fact that FINA does not stipulate particular rules for age-grouping provides notable characteristics of age-grouping systems among federations, such as 1) the number of age-groups, 2) sex-dependent or independent groups, 3) single-age-based qualification times regardless of age-groups, and 4) local/provincial organization-determined systems. These are conceivably derived as a means of reinforcement and enlivenment of youth swimmers. For instance, combining multi-ages into groups appears to be an attempt to provide a higher competitive field for swimmers although the multi-age-grouping reduces the chance of success for younger swimmers within age-groups. Moreover, since girls, on average, reach maturity sooner than boys, and therefore potentially have less variation in sports performance among older individuals (Malina et al., 2004), they could be classified into a multi-age-group at an earlier age than boys.

Using multi-age classification addresses the issue of younger swimmers being discouraged until they "age up." It is not uncommon for young swimmers to terminate their competitive swimming careers when they move up to older multi-age-groups; thus being at the "bottom of their age-group," where they feel they can no longer compete successfully. This coincides with a greater time demand for academics and schoolwork. Lack of success at higher levels of competition causes swimmers to reevaluate their interests. In light of these logistic and maturational factors, Kojima et al. (2009) have suggested an alternative age-grouping system: 1) using single CA category (at least, up to age 14 years in girls and 16 years in boys), 2) sex-dependent groupings, and 3) a single unisex group for girls and boys aged 7 years and under. These ideas may not address all inherent issues of grouping adolescent swimmers by CA, but may better ensure fairness and equality in competition than the current paradigms in use today.

Lastly, that FINA does not control worldwide age-grouping rules may be logically appropriate. From the point of view of documented ethnic variation in timing of growth and maturation (Eveleth & Tanner, 1990; Malina et al., 2004), it would be unreasonable to adopt a universal age-grouping paradigm. Data have shown that maturational events occur at early ages in Asian and Black-American children when compared with European and American Caucasian children. There seems to be approximately a 1-year difference in the age at PHV between these ethnic groups. The mean age of Asian and European/North American swimmers at the 2nd FINA Youth Championships was 15.7 ± 1.1 years for Asians girls and 16.2 ± 0.9 years for Caucasians girls (p < 0.05). The Asian boy swimmers were also younger (16.9 ± 1.0 years vs. 17.6 ± 0.6 years, p < 0.05). Due to maturation-related competitive advantages in early matures over late and/or average matures (Malina et al., 2004), the ethnic differences may be an interesting consideration in predicting performance outcomes at international competitive events.

**CONCLUSION**

Age classification systems clearly influence participation and competition outcomes in competitive youth swimming. The number of swimmers qualifying for competitive events and then qualifying for finals at international events is significantly greater for swimmers who are the oldest in their age-groups. Grouping swimmers by the use of broad CAs is not the optimal way to encourage younger competitors. With today's computing power and software sophistication, novel strategies are available to group swimmers without affecting the meet timeline or expense. These new innovative strategies may act to enhance competition and encourage participation.

**REFERENCES**


Fédération Internationale de Natation: http://www.fina.org


269
Effects of Reduced Knee-bend on 100 Butterfly Performance: A Case Study Using the Men’s Asian and Japanese Record Holder

Ide, T.1, Yoshimura, Y.2, Kawamoto, K.3, Takise, S.1, Kawakami, T.1

1 Osaka University of Health and Sport Sciences, Osaka, Japan.
2 Chuo University, Tokyo, Japan.
3 Phoenix Swim Club, Phoenix, Arizona, USA

This article analyzed the 30 year old Asian and Japanese record holder of the men’s 100 meter butterfly. In 2002, Kohei Kawamoto’s best time was 53.22 seconds, and he improved his time to 51.00 seconds in 2009. The most significant difference between Kohei in 2002 and 2009 was the focus on a straight leg butterfly kick technique. When comparing his 2005 stroke to his 2009 stroke, we found that the extent of the straightness of his butterfly kick improved from 39% to 55% (of >170 degrees knee-bending). Additionally, this swimmer improved his speed from 2.5m·s⁻¹ to 2.7m·s⁻¹, and increased his distance per stroke from 1.894m±0.062 to 2.204m±0.131.

Key words: Training, Asian and Japanese National Record, Butterfly, Straight kick, Coaching, Swimming Speed Meter.

INTRODUCTION

Butterfly swimmers should keep their body as horizontal as possible during the propulsive phase of the arm stroke (Maglischo, 2003). In general, coaches use the technique of ‘wave butterfly’ (Japan Swimming Federation, 2006), and the dolphin kick technique of bending the knees. The wave butterfly arises from body movement, arm-stroke timing and kick timing (Yoshimura, 1996). Bending the knees during the butterfly kick increases the undulation of ‘wave butterfly’. Coaches still use the technique of bending the knees during the butterfly kick, with the purpose of pushing back the water (Fig.2).

Since 2006, we coached Kawamoto to change his butterfly technique, employing a straighter leg-kick. The result was a more horizontal stroke. Kawamoto’s initial butterfly kick technique used a bending butterfly kick. We changed this to a straighter kick with less knee-bend (Yoshimura, 2008), which is imagined as ‘holding the water to the bottom of the pool’ (Fig. 1).

METHODS

Kohei Kawamoto, 30 years old Asian and Japanese record holder of the men’s 100 meter butterfly (height; 174 cm, body weight; 64kg) volunteered to participate in this study. A comparison was made of Kawamoto’s performance in 2009 to his previous performance in 2005. He performed 4 times 25 meter butterfly swims, whilst being filmed, from a push start. The first 15 meters were completed under water using the butterfly kick and the final 10 meters swimming all out butterfly stroke. A Swimming Speed Meter (Vine, VMS-003, AC100V, 1/500s, 0.2mm/pulse) using a wire attached to the swimmer, exported the analogue signals via an RS232C post to a computer. These signals were used to calculate swimming speed (Microsoft Windows Excel; Yoshimura, 2007). The wire line of the speed meter was attached to the swimmer by a belt and intracyclic velocity changes were recorded precisely for several stroke cycles while swimming at maximum speed. The average velocity changes for one stroke cycle were calculated with data from all successive stroke curves. The average number of stroke cycles were compared (for the 2009 stroke and 2005 stroke). A Swimming Speed Meter, registered velocity when the subject was at maximum speed within one stroke cycle, which is during the second kick phase. Then comes the wave phase, and first kick phase, insweep phase. During swimming, the subject was monitored from the side plane using an underwater video camera at a sampling frequency of 60Hz (Underwater monitor system 2, YAMAHA, Shizuoka, Japan). The angle of the knee bend and upper body movement were analyzed with the DartTrainer.

RESULTS

The Swimming Speed Meter showed that swimming speeds increased from 2.5m·s⁻¹ for 2005 to 2.7m·s⁻¹ in 2009 (during the second kick phase). Distance per stroke (DPS) increased to 2.204m±0.131 for 2009, from 1.894m±0.062 in 2005 (m) Wilcoxon.: p=0.006061, 1 stroke (velocity) Wilcoxon.: p=0.7748) (Figure 3.). Four phases of the 2009 and 2005’s velocity results were not significantly different (the first kick phase Wilcoxon: p=0.64850, insweep phase Wilcoxon: p=0.16360, up-sweep and second kick phase Wilcoxon: p=0.00606, wave phase Wilcoxon: 0.10910.)
In 2006, Kawamoto changed his stroke technique to a straighter knee angle, defined as 170 degrees to 180 degrees (+170 degrees) and 55% of the stroke cycle was spent within this 'degree of bend' for 2009 whereas it was only 39% in 2005 (Table 1.). Therefore, 2009's stroke, with the straight knee technique, decreased the resistance during his stroke and as a result, increased his distance per stroke and maximum speed.

**DISCUSSION**

Based on the above evidence it is clear the most preferred butterfly technique is to use a straight knee kick. The men’s 100 butterfly world record holder, Michael Phelps employed this stroke technique with the straighter knee (+170 degrees) and 49.6% of the stroke cycle was spent within these ‘degrees of bend’. Mike Cavic, 2nd in the men’s 100 butterfly 2008 Olympic Games, employed the straight knee kick and 55% of his stroke cycle was at >170 degrees knee-bend. The men’s 100 butterfly former world record holder, Ian Croker employed showed 48% of his stroke cycle at >170 degrees knee-bend. Since 2006, we employed a four step training plan in practice and in swimming competition (Ide, 2009). In the first step, we imagined the straighter kick on land. On land, we focused on the butterfly straight leg kick, stretching the tendon of the tibialis anterior muscle rather than using the quadriceps muscles (Huijing, 1992). When Kawamoto used this stretched tendon in a similar way in the butterfly straight leg kick, the kick frequency was much more rapid (Hosokawa, 2009). The second step was to utilize the straight leg kick in the pool, and this involved slow speed drills during training. We changed his technique during training, so these drills involved swimming no more than 3500m. If he swam more than 3500m he had a tendency to bend the knees and move the upper body too much. Also, these sessions were performed just once a day. The third step was to test the technique in a minor meet. After the race, we checked these techniques by the video camera. Then we would check these techniques from the minor meet and insure they are correct in preparation for the next step. The fourth step was the major meet, which will be the Olympic Trials, World Championship Trials, Japan Nationals, World Championship, East Asian Games or Japan Open. His training partner won and set a meet record at the 2009 US Junior Nationals men 100Fly.

**CONCLUSION**

This study analyzed the butterfly stroke technique of Japan’s 100 meter butterfly record holder. Kawamoto improved his performances, due to three possible reasons: 1. increased maximum speed, from 2.5m·s⁻¹ to 2.7 m·s⁻¹. 2. increased distance per stroke, from 1.894m±0.062 to 2.204m±0.131 . 3. Use of the straight knee dolphin kick.

**REFERENCES**


**ACKNOWLEDGEMENTS**

I would like to express my heartfelt appreciation to the many people who supported this research. Thanks to the Tokyo Institute of Swimming Science, who allowed us to use Kawamoto’s data since 2005. They had control of the Swimming Speed Meter. Also Mr. Tetsuya Tanaka, who was calculated Kawamoto’s data with the Wilcoxon Signed Ranked Test. And Hamamatsu Photonics K.K. (Hamamatsu Swim Stroke Watcher) Mr. Takehiro Kurono, who had supported Kawamoto’s race data.
Stability and Prediction of 100-m Breaststroke Performance During The Careers of Elite Swimmers

Costa, M.J.1,4; Marinho, D.A.1,4; Reis, V.M.1,4; Silva, A.J.1,4; Bragada, J.A.1,3; Barbosa, T.M.1,4

1 Polytechnic Institute of Bragança, Bragança, Portugal
2 University of Beira Interior, Covilhã, Portugal
3 University of Trás-os-Montes and Alto Douro, Vila Real, Portugal
4 Research Centre in Sports, Health and Human Development, Vila Real, Portugal

The aim of this study was to track and analyze the 100-m Breaststroke performance stability throughout elite swimmers’ careers. 35 Portuguese male top-50 swimmers were analyzed for seven consecutive seasons between the ages of 12 and 18 years old. Best performances were collected from ranking tables. Longitudinal assessment was performed based on two approaches: (i) mean stability was analyzed by descriptive statistics and ANOVA repeated measures for each season followed by a post-hoc test (Bonferroni test), (ii) normative stability was analyzed with self-correlation (Malina, 2001) and the Cohen’s Kappa tracking index (Landis and Koch, 1977). There was a 100-m Breaststroke performance enhancement from child to adult age. The overall career performance prediction was low. The change from 13 to 14 years can be a milestone, where the ability to predict the final swimmer’s performance level strongly increases.

Keywords: stability, prediction, tracking, breaststroke

INTRODUCTION

Swimming seems to be one of the most studied sports in the Sport Sciences community. Researchers are constantly trying to identify and understand the factors that can better predict swimming performance. However, the majority of the studies in swimming “science” have a cross-sectional character. Indeed, they do not consider the performance stability and change as the result of individual development, new training methods and/or technological sophistication.

The longitudinal approaches regarding competitive swimming are few. Even so, most of the papers published have a strong focus on physiological and/or biomechanical issues and less on the swimming performance itself. Swimming performance is expressed by the time spent to cover the event distance. The longitudinal performance assessment is important to help coaches to define realistic goals and training methods. These longitudinal assessments can be developed tracking the performance of elite swimmers, analyzing its progression between competitions and/or seasons. The main advantages are that it is possible to: (i) describe and estimate the progression and the variability of performance during and between seasons; (ii) find hypothetical chronological point determinants to predict swimmer’s performance throughout his/her career or a given time frame and; (iii) determine swimmer’s chance to reach finals or win medals in important competitions. Pyne et al. (2004), in a 12 month study, made an attempt to understand the performance behaviour leading up to the 2000 Olympic Games by analyzing the 50-m, 100-m, 200-m, 400-m, 800-m (females only) and 1500-m (males only) freestyle events; two backstroke, breaststroke and butterfly events over 100-m and 200-m, and the 200-m and 400-m individual medley events. They reported that to stay in contention for a medal, a Sydney 2000 Olympic swimmer should improve his/her performance by approximately 1% within a competition and by approximately 1% within the year leading up to the Olympics. The authors also stated that presumably an additional enhancement of approximately 0.4% would substantially increase the swimmer’s chances of a medal.

So far, any research analyzing the change and stability of swimmer’s breaststroke performance during his/her career using the tracking approach does not appear to exist. Therefore, the purpose of this study was to track and analyze the 100-m male breaststroke performance stability throughout the elite swimmer’s career, from childhood to adult age.

METHODS

An overall of 35 Portuguese male swimmers and 905 race times were analyzed for seven consecutive seasons between 12 and 18 years old. The Portuguese male top-50 rankings in the 100-m Breaststroke event, in the 2007-2008 season was consulted to identify the swimmers included. Exclusion criteria were defined as: (i) authors do not have access to the season best performance in seven consecutive seasons and (ii) swimmer did not swim the 100-m breaststroke event at least once per season for some reason. Best performances from official competitions, in a short course pool (regional, national or international level), during the career seasons, were collected from ranking tables. The rankings tables were provided by the Portuguese National Swimming Federation, and when suitable or appropriate were also consulted from a public swimming database (www.swimrankings.net, November 2009).

Longitudinal assessment was performed based on two approaches: (i) mean stability; (ii) normative stability. For mean stability, quartiles, means plus standard deviations were computed for each chronologically age. Data variation was analyzed with ANOVA repeated measures followed by a post-hoc test (Bonferroni test). Normative stability was analyzed with Pearson Correlation Coefficient between paired performances throughout the seven seasons. Qualitatively stability was considered to be: (i) high if $r \geq 0.60$; (ii) moderate if $0.30 < r < 0.60$ and; (iii) low if $r < 0.30$, as suggested by Malina (2001). The Cohen’s Kappa tracking index (K) plus one standard deviation, with a confidence interval of 95% was also calculated. The qualitative interpretation of K was made according to Landis and Koch (1977) suggestion, where the stability is: (i) excellent if $K \geq 0.75$; (ii) moderate if $0.40 \leq K < 0.75$ and; (iii) low if $K < 0.40$.

All statistical procedures were computed with SPSS software (v. 13.0, Apache Software Foundation, Chicago, IL, USA). However, the K value was computed with the Longitudinal Data Analysis software (v. 3.2, Dallas, USA). The level of statistical significance was set at $P \leq 0.05$.

RESULTS

Figure 1 presents the variation of swimming performance throughout swimmer’s career. ANOVA repeated measures revealed significant variations in the 100-m Breaststroke swimming performance [$F (1.34) = 353.57; P < 0.01, power = 1.00$]. Bonferroni post-hoc tests verified significant differences ($P < 0.01$) between all seasons analyzed. The only exception was for the pair wise comparison between the sixth and the seventh seasons that was not significant. From the age of 12 to the age of 18, median values ranged between 80.70 s (12 years) and 66.55 s (18 years). So, there was an obvious performance enhancement during the swimmer’s career.

Figure 1: Diagram of 100-m Breaststroke swimming performance, median extremes and quartiles from childhood to adult age.
The K value, expressing the stability throughout the overall swimmer's career, was moderate (K = 0.38 ± 0.05) with 0.33 ≤ K ≤ 0.43 for a 95% confidence interval. So, based on overall values of the seven consecutive seasons, a low swimming performance stability and prediction can be considered.

Table 1 presents the self-correlation values for paired ages throughout swimmer's career. Self-correlations were significant in all situations (P < 0.05), except between the 16 and 17 years. Overall, throughout swimmers career, self-correlation ranged between a moderate and a high stability (0.30 ≤ r ≤ 0.60). Indeed, most of the pair wise self-correlations were r = 0.60. Stability becomes high (r = 0.644) from 14 until 18 years old.

Table 1: Pearson Correlation Coefficients from children to adult age in the 100-m Breaststroke event.

<table>
<thead>
<tr>
<th>Age</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>0.863*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.610*</td>
<td>0.850*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.459*</td>
<td>0.722*</td>
<td>0.867*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.300</td>
<td>0.582*</td>
<td>0.741*</td>
<td>0.728*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>0.300</td>
<td>0.505*</td>
<td>0.696*</td>
<td>0.678*</td>
<td>0.802*</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>0.398*</td>
<td>0.485*</td>
<td>0.644*</td>
<td>0.598*</td>
<td>0.730*</td>
<td>0.839*</td>
</tr>
</tbody>
</table>

* P < 0.05

DISCUSSION

The aim of this study was to track and analyze the 100-m Breaststroke performance stability throughout the elite swimmer's career. Main data suggests an obvious performance enhancement in the 100-m Breaststroke event, from children to adult age. Analyzing the overall tracking values, the prediction of adult swimmer's performance level, based on childhood performance is moderate. When more strict time frames are used, swimming performance stability and prediction increases starting at the age of 14. It seems that the change from 13 to 14 years can be a milestone, where the ability to predict the swimmer's performance level strongly increases.

The trend for performance enhancement throughout swimmer's career might be associated to some scientific improvements and innovations that along with the normal individual development process, allow swimmers to obtain better performances. As swimming performance is determined by different parameters, the individual development will affect the energy cost of swimming (Kjendlie et al., 2003). Changes in anthropometric characteristics, like body length and body mass, are identified as causes to increase energy cost (Chatard et al., 1985). Along with these morphological changes, development shows an increase in swimmers muscular strength. It appears that hormonal development that occurs during maturation has a determinant role in increasing muscle size and strength (Matos and Winsley, 2007). Furthermore, the sequence in which training loads or volumes are applied, as a series of training blocks, is critical to enhance performance. The model of training load reduction adopted before important competitions has a high effect on the athlete's performance (Mujika et al., 2002). This type of training reduction is not common in younger ages.

Another explanation for this career improvement is the technological sophistication of the swimming suits. The type of material (e.g. polyurethane), the ways to sew the fabric pieces, suit types and sizes, the effect of swim suits upon wobbling body mass, and body compression might explain the major advantages of wearing these recently developed suits leading better performances in adult ages (Marinho et al., 2009).

However, despite this performance improvement during the swimmers career, a slight "breaking effect" starting at the age of 16 (Figure 1) can be observed. This fact may be associated with: (i) a maximal level of external training load reached by the swimmers, which is more difficult to overcome; (ii) a decrease in physiological functional capacity with age; or, (iii) a slowdown or stagnation in the development of anthropometric characteristics.

The self-correlation values (Table 1) ranged between moderate and high stability throughout the swimmer’s career. The initial sharp increase in stability can be observed during the change from 13 to 14 years old. This can be explained by: i) maturational process, that provides greater availability for training process, in order to obtain more ambitious performances, ii) consolidation of values and culture of swimming performance acquired throughout swimmer’s career.

The K value, expressing the stability throughout the overall swimmer’s career, was low (K = 0.38 ± 0.05). Based on such long careers, it is clear that swimmers performance stability is difficult to maintain on a high level. Moreover, there are several episodes that can influence the performance stability, such as illness or an acute/chronic injury. When more strict time frames are used, performance stability and prediction increases.

CONCLUSION

The prediction of adult performance level, based on childhood performance is low, when considering the swimmer’s overall career. When more strict time frames are used, swimming performance stability and prediction increases starting at the age of 14. It seems that the change from 13 to 14 years can be a milestone, where the ability to predict the final swimmer's performance level strongly increases.

REFERENCES


ACKNOWLEDGMENTS

Mário J. Costa would like to acknowledge to the Portuguese Science and Technology Foundation (FCT) for the PhD grant (SFRH/BD/62005/2009).
Effect of Subjective Effort on Stroke Timing in Breaststroke Swimming

Ohba, M.¹, Sato, S.¹, Shimoyama, Y.², Sato, D.²

¹ Niigata University, Niigata, Japan
² Niigata University of Health and Welfare, Niigata, Japan

This study examined the relationship between stroke timing and subjective effort during breaststroke swimming (BR) in comparison with front crawl swimming (FC). Eight 25-m swim trials were conducted, consisting of two styles (FC and BR) and four levels of subjective effort. The levels were four steps from 70–100% effort with the same clearance for one's maximal effort. A significant positive correlation was found between subjective effort and SV. Increasing and decreasing the swimming velocity depends remarkably upon SR, not only for FC but also for BR. However, a significant interaction was found for SV. No significant interaction was found for SR. Both strokes have the same ratio of SR increase as stepping up the subjective effort, but not the same ratio of SV increase. Results show that the degree of SV increase by SR increase in BR is less than in FC, which might be attributed to technical characteristics.

Key words: subjective effort, breaststroke, grading, output intensity

INTRODUCTION
It is important for competitive swimmers to subjectively control their output. To do so, they must have the capacity of changing swimming speed. It is difficult for athletes to control their own motion because they attempt to control their own motion depending on subjective sensations. They might be surprised by the difference between actual motion and imaging when they confirm their motion displayed on a monitor. Such a difference might engender poor results in competitive swimming. The relation between subjective sensations and the actual output intensity is strongly associated with the ability to grade. Some reports of studies of grading for swimming (Goya et al. 2005, 2008) have described that the subjective effort was correlated significantly with objective intensity at given conditions during 50 m crawl swimming in male and female subjects. However, no reports in the literature describe the effects of subjective effort in the timing of breaststroke swimming. This study was undertaken to examine the relation between stroke timing and subjective effort during BR in comparison with FC.

METHODS

Subjects
In this study, 22 well-trained college swimmers (11 male, 11 female) participated after giving their consent. Their main characteristics were the following: age, 19.5±0.7 y; height, 176.5±5.0 cm; mass, 69.4±4.0 kg; and age, 20.2±0.5 y; height, 163.6±5.3 cm; mass, 59.3±5.2 kg.

Experimental schema
Figure 1 presents the experimental design. After 30 min free warm-up, each was asked to swim at an imposed subjective effort of "maximal". Eight 25-m swim trials were conducted in all, which consisted of two swimming styles (FC and BR) and four levels of subjective effort. The levels were four steps—from 70% to 100% effort. The maximal effort trial was conducted on the fourth trial with each style. Other levels of effort were selected arbitrarily. Subjects were given 5–6 min rest between trials.

Subjects were instructed as follows: 1) Swim with your subjective feeling only. 2) Do not speak about your own or another subject's performance. 3) Swim with your highest concentration. Subjects were not informed of their swimming time after each trial.

RESULTS AND DISCUSSION
A significant positive correlation was found between subjective effort and SV (Fig. 3). The regression equations of FC and BR were, respectively, Y=0.67X+0.335 (r=0.99, p<0.01) and Y=0.42X+0.587 (r=0.97, p<0.01). Furthermore, a significant positive correlation was found between subjective effort and SR (Fig. 3). The regression equations of FC and BR were Y=0.85X+0.155 (r=0.99, p<0.01) and Y=0.78X+0.225 (r=0.99, p<0.01) of BR. The first important finding of this study is that subjective effort and SV were highly correlated (FC, r = 0.99; BR, r = 0.97). It was confirmed that the subjective output was correlated significantly with objective intensity at given conditions. The increase and decrease of the swimming velocity greatly depends upon SR, not only for FC but also for BR.
CONCLUSION

In conclusion, increasing and decreasing the swimming velocity depends mostly upon SR, not only in FC but also in BR. However, the degree of SV increase by SR increase in BR is expected to be less than in FC. These results suggest that changing the swim speed by changing the subjective effort in a race or in training can be considered a change of coordination (style).

REFERENCES


Models for Assessing General Horizontal Swimming Abilities of Junior Water Polo Players According to Playing Position

Özkol, Z. 1, Dopsaj, M. 2, Thanopoulos, V. 3, Bratusa, Z. 2

1Ege University Physical Education and Sport Department, Izmir, Türkiye. 2University of Belgrade Faculty of Sport and Physical Education, Belgrade, Serbia. 3University of Athens Faculty of Physical Education and Sports Sciences, Athens, Greece.

The aim of this study was to identify general level of horizontal swim abilities of junior water polo players according to playing position. The subjects consisted of 71 players aged 15-16, members of national junior teams. The players were divided into three playing position groups; peripherals (P), center defenders (CD) and center players (C). The following six swimming tests were performed: crawl; 15m, 25m, 50m, 200m, 25m crawl with head up and 25m crawl with ball. The results of these tests were analyzed using a confirmative model of factor analysis for the determination of the factor scores and mathematical multidimensional procedures were determined for creating models. There were no statistical differences (p>0.05) between general level of basic horizontal swim abilities according to position.

Key words: Waterpolo, playing position, junior, model assessment, swim test.

INTRODUCTION

Tactical, technical, physical demands and also playing position differences of water polo players are very important factors for competitive success. For the planning of water polo training, the primary informative sources need to be taken into consideration, the physiological demands of the game, based on the differences in game duration, the period of the game, the level of competitiveness of the players, the level of competitiveness of the teams and the different player positions (Lozovina, 1983; Lozovina et al., 2009; Platanou, 2009; Tiekouras et al., 2005).

Certain activities are performed more frequently and with an increased overall duration by the center forwards compared to attackers and defenders (Platanou, 2009). However, very few studies have been published about the anthropometrical, physical and physiological parameters of water polo players at various ages. Bratusa (2000) found that water polo training affects basic motor skill improvement in prepubescent children. Matković et al. (1999) suggest using specific tests on land and in the water. Through training and selection, an early specialization takes place and those boys who are more skillful in specific situations stand out. Falk et al. (2004) recommend using fewer swimming tests in the selection process of young water polo players. In high profile water polo, using manifest anthropometric and motor skills variables, it is possible to make a prognosis of how successful any defense/offense will be (Lozovina, 1983).

However, there is little data about horizontal swimming abilities according to playing position in the younger categories, especially cross culturally. There is also a lack of research on how to identify horizontal swimming abilities according to playing position differences of water polo players. Therefore the aim of this study was to identify the general level of horizontal swim abilities of junior water polo players according to playing position and to improve our understanding of the positional differences of water polo players.

METHODS

The subjects consisted of 71 players aged 15-16, members of national junior teams from: Slovenia, Turkey, Serbia and Greece. For the play-
of 16 yrs old water polo players were created, as three different multidimensional models for prediction of basic horizontal swimming abilities (F=0.390, p=0.678), 25m crawl (F=0.027, p=0.974), 15m crawl (F=0.078, p=0.925), 25m crawl (F=0.209, p=0.812), 50m crawl (F=0.253, p=0.777), 100m crawl (F=0.641, p=0.530), 25m crawl (F=0.390, p=0.678), 25m crawl (F=0.027, p=0.974) three different multidimensional models for prediction of basic horizontal swimming abilities for 16 yrs old water polo players were created, as Horizontal Swim Score (HSS).

The ANOVA regression analysis results show that the separated set of 6 predicting variables statistically significantly describes the HSS (P), HSS (CD) and HSS (C) at the level p=0.000. The model explains 100% of all three playing positions, variability with value of standard estimation error of ±0.00307%, ±0.00213% and ±0.00255% of horizontal swimming ability, respectively. It can be considered that the calculated model is useful and reliable since the standard estimation error is lower than the standard error (SD) HSS (P)=17.48%, HSS (CD)=16.28% and HSS (C)=15.81%.

Table 3 shows the results of multiple regression analysis for variables which by regression model method, defined the model of mathematical regression equations. From this model the set of 6 variables which make up the complex of horizontal swimming abilities, (which depend on each player's positional role (Smith, 1998). Different positions in water polo have their specificities that should be responded to by the players who play in those positions (Bratusa and Dopsaj, 2006).

**DISCUSSION**

Competitive water polo can be characterized as a physiologically demanding intermittent activity, mainly relying on players' aerobic power and lactic acid threshold (Hohmann and Frase, 1992, Platanou and Gelas, 2006) and a sport that requires a variety of technical skills and athletic abilities that depend on each player's positional role (Smith, 1998). However, Hohmann and Frase (1992) reported no significant differences in the swimming intensity or the distance covered among various field positions among senior players. Our findings point out no swimming ability differences between players who play three different positions. Based on the analysis made, no statistical differences were found between peripherals, defenders and centers in HSS. Although there were mathematical differences in HSS between players playing three different positions, HSS figures were still very close to each other. As expected the best scores in HSS belonged to peripherals followed by centers and then center defenders.

Prior to our analysis, it was estimated that peripherals would perform much better when compared to the other two positions but our findings did not confirm this. Peripherals usually stand out with their ability play a faster game, better reflexes, better swimming performance, more drives in the pool. Taking into account all of this, it was expected that their scores would be much better than centers and center defenders. The latter two are accustomed to do more one-on-one battle due to their position in the game and this builds up power and strength for the players in these positions.

However the findings did not entirely follow the hypotheses and theory. Especially when looking at their alactic swimming skills, there were no major differences between these three position. In fact, the center defenders showed better performance on the alactic swimming ability than the peripherals.

Based on all of the findings above, it was found that players do not exhibit specific swimming characteristics associated with their position at the youth national team level.

On the other hand Bratusa and Dopsaj (2006) reported that there definitely are differences in swimming features of the players in different positions of junior Slovenian players. A greater number of swimming efforts (Dopsaj and Markovic, 1994; Sarmento, 1994; Smith, 1998) in the wing positions and a greater number of duels particularly in center and back positions caused the greatest differences exactly between these positions (Bratusa et al., 2003; Sarmento, 1994; Smith, 1998).

Different positions in water polo have their specificities that should be responded to by the players who play in those positions (Bratusa and Dopsaj, 2006).

**REFERENCES**


A Markov Chain Model of Elite Water Polo Competition

Pfeiffer, M., Hohmann, A., Siegel, A., Böhnelein, S.

Institute of Sport Science, University of Bayreuth, Bayreuth, Germany

When it comes to water polo, performance diagnostics offers many different methods to analyze a game. In this context, problems mostly occur in adequately modeling the game, in part because the various approaches lack scope for uniform performance criteria. In this study, the concept of match-play analysis through mathematical simulation by means of the Markov-chain model was applied to water polo and used to analyze the performance relevance of tactical behaviour patterns at the World League Final 2007 (Berlin) with focus on the German and Serbian teams. The results suggest that in international-level water polo, the performance relevance of "Turn over to counter attack" and "Turn over to One-center-attack" were the most worthwhile tactical behaviour patterns. No significant differences between Germany and Serbia could be found.

Key words: game analysis, water polo, tactical behaviour, simulation, Markov chain

INTRODUCTION

From a performance diagnostic point of view, the key task of notational analysis is to analyze the game structure and find determining factors, in this case tactics, of performance. A look at the literature shows that a large number of methods have been developed – based on rapid technological developments in the area of computers, video etc. – to analyze the structure of game sports by game observation, in order to identify performance indicators (Hughes & Bartlett, 2002). A comprehensive review of the evolution of notational analysis in sports games is given by Hughes and Franks (2004), Hughes (2008) and Hughes and Bartlett (2008). Most of these methods use structure-oriented observation models, which enable the researcher to register isolated elementary actions in a match, but do not allow for the obtaining of data on the interaction process itself.

Considering a sports game as a dynamic system or an interaction-process, different stochastic models have been developed. The models of the finite Markov chain were successfully applied to describe and predict playing profiles or patterns (McGarry & Franks, 1994; McGarry & Perl, 2004), and to determine the performance relevance of tactical behaviour (Hirotsu, Miyaji, Ezake, Shigenaga & Taguchi, 2004; Hohmann, Zhang & Koth, 2004; Lames, 1991; Zhang, 2003). In the game analysis approach of Lames (Lames, 1991; Lames & McGarry, 2007), comparable quantitative values for the performance relevance of selected tactical patterns are determined by the method of simulation. The concept of performance analysis through mathematical simulation by means of the Markov chain model was first established in the area of return games and successfully transferred to invasion games (e.g. handball and soccer; Pfeiffer, 2004; Pfeiffer, 2005; Pfeiffer & Hohmann, 2008). In this study, the same approach was applied to water polo to analyse the relevance of specific tactical behaviour to performance in general and with focus on the German and Serbian Water Polo teams at the World League Final 2007 in Berlin.

METHODS

Observation model: The water polo match is described as a system that gradually moves through different states. The starting point of our observation model was the possession of the ball (state "Turn over"). The offensive play was modelled on the basis of all offensive attempts, which were characterized by 16 different states of the game. These states represent different player positions in even-man offense (6–6; position at-
tack and double-center attack) and one man-up offense (6–5) as well as specific game situations (turn over, driving-in, and goal/penalty) (Table 1). The final state of “goal/penalty” is defined as the criterion of performance, necessary for judging the performance relevance of all other tactical behaviour. The typical tactical behaviour of the teams is expressed in the transition between two subsequent states (“tactical patterns”).

Table 1. State model used for game analysis in water polo (for both teams)

<table>
<thead>
<tr>
<th>No.</th>
<th>State Abbrev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Turn over TO</td>
</tr>
<tr>
<td>2</td>
<td>Counter-attack CA</td>
</tr>
<tr>
<td>3</td>
<td>One-center-attack OCA</td>
</tr>
<tr>
<td>4</td>
<td>Back-position in OCA BPOCA</td>
</tr>
<tr>
<td>5</td>
<td>Flanker-position OCA FPOCA</td>
</tr>
<tr>
<td>6</td>
<td>Center-position in OCA CPOCA</td>
</tr>
<tr>
<td>7</td>
<td>Driving-in DI</td>
</tr>
<tr>
<td>8</td>
<td>Double-center-attack DCA</td>
</tr>
<tr>
<td>9</td>
<td>Back-position in double-center attack BPDCA</td>
</tr>
<tr>
<td>10</td>
<td>Flanker-position in double-center attack FPDCA</td>
</tr>
<tr>
<td>11</td>
<td>Center-position in double-center attack CPDCA</td>
</tr>
<tr>
<td>12</td>
<td>Man-up-Attack MUA</td>
</tr>
<tr>
<td>13</td>
<td>Back-position man-up (BPMUA) BPMUA</td>
</tr>
<tr>
<td>14</td>
<td>Flanker-position man-up (FPMUA) FPMUA</td>
</tr>
<tr>
<td>15</td>
<td>Center-position man-up (CPMU) CPMUA</td>
</tr>
<tr>
<td>16</td>
<td>Goal/penalty G</td>
</tr>
</tbody>
</table>

Stochastic model: The transition probabilities between two states describe the water polo match as a process that can be understood as a first order Markov chain, when the following two properties are given: (1) the probability for the next state depends only on the current state (Markov-property), and (2) the transition probability from one state to another is independent of their chronological position in the match process (chain-property).

The transition probabilities between the states can be transformed into a two dimensional transition matrix. Each element of this matrix has the property \( p_{ij} \geq 0 \) and the line sum is equal to 1. In the theory of a Markov chain, several kinds of states are distinguished. Absorbing states are important, because the process ends in these states, and a new process starts. For our purpose of performance diagnosis, the state “goal/penalty” is defined as the absorbing state. The transition probability to the absorbing state is called the goal probability (GP). The GP can be calculated for both opponents by multiplication of a start vector (distribution of the states) with the observed (empirical) transition matrix. In so-doing, the probabilities for the absorbing condition of “goal/penalty” are attained for both teams.

Simulation to quantify the performance relevance of tactical behaviour patterns: Based on the empirical transition matrix of a water polo match, it is also possible to calculate the GP on the basis of a numerically manipulated (simulated) transition matrix. In order to determine the performance relevance of a tactical behaviour pattern of interest, the empirical transition probability between these two states was manipulated by a certain percentage in each observed match. After this the goal probability was calculated and defined the performance relevance (6GP) of a tactical behaviour pattern as the difference between the goal probability (GP) as calculated by the original (observed) transition-matrix and the goal probability as calculated by the manipulated transition-matrix.

With reference to this simulation method there are two special problems: (1) to find the adequate quantitative size of the manipulation of the investigated transition probability, and (2) to establish an algorithm that determines how the other (not manipulated) transition probabilities have to be changed, so that the stochastic character of the matrix (sum of each row equals 1.00) is preserved. Regarding (1); according to Lames (1991), the function to deflect the transition probabilities is: \( \delta TP = C \cdot B \cdot 4 \cdot TP \cdot (1-TP) \). TP is the transition probability and \( \delta TP \) the change of the transition probability of the investigated tactical pattern. The constant values applied in the present study were \( C = 1 \) and \( B = 5 \), which were also determined by Lames (1991) and thoroughly tested by Pfeiffer (2004, 2005).

Regarding (2): each compensation procedure was based on a proportional compensation of all other transition probabilities, as no a priori information existed to justify any targeted compensation: \( \delta TP = -(TP/(1-TP)) \cdot \delta TP \). Figure 1 demonstrates how the performance relevance (6GP) of a tactical behaviour is calculated by a simulation on the basis of a standardized manipulation of the transition probability.

The differences between the German and Serbian teams were analyzed by \( t \)-test (independent two-sample). In all tests, \( p < 0.05 \) was accepted as significant.

RESULTS

In the present study, eleven matches of the World League Final 2007 in Berlin were analysed in regard to eleven tactical patterns (transition probabilities) (Table 2).

Table 2. Analysed tactical patterns (in each case for both teams)

<table>
<thead>
<tr>
<th>No.</th>
<th>Tactical pattern (transition)</th>
<th>Abbrev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Turn over – Counter-attack</td>
<td>TO-CA</td>
</tr>
<tr>
<td>2</td>
<td>Turn over – One-center-attack</td>
<td>TO-OCA</td>
</tr>
<tr>
<td>3</td>
<td>Back-position – Center-position (both One-center-attack)</td>
<td>BPOCA-CPOCA</td>
</tr>
<tr>
<td>4</td>
<td>Back-position (One-center-attack) – Driving-in</td>
<td>BPOCA-DI</td>
</tr>
<tr>
<td>5</td>
<td>Back-position (One-center-attack) – Double-center attack</td>
<td>BPOCA-DCA</td>
</tr>
<tr>
<td>6</td>
<td>Back-position (One-center-attack) – Man-up-attack</td>
<td>BPOCA-MUA</td>
</tr>
<tr>
<td>7</td>
<td>Flanker-position – Center-position (both One-center-attack)</td>
<td>FPOCA-CPOCA</td>
</tr>
<tr>
<td>8</td>
<td>Flanker-position (One-center-attack) – Driving-in</td>
<td>FPOCA-DI</td>
</tr>
<tr>
<td>9</td>
<td>Flanker-position (One-center-attack) – Double-center attack</td>
<td>FPOCA-DCA</td>
</tr>
<tr>
<td>10</td>
<td>Flanker-position (One-center-attack) – Man-up-attack</td>
<td>FPOCA-MUA</td>
</tr>
<tr>
<td>11</td>
<td>Center-position (One-center-attack) – Man-up-attack</td>
<td>CPOCA-MUA</td>
</tr>
</tbody>
</table>

The differences between the German and Serbian teams were analyzed by \( t \)-test (independent two-sample). In all tests, \( p < 0.05 \) was accepted as significant.
Objectivity of the game observation model: The instrumental consistency of the observation model (objectivity) was examined by the inter-rater consistency (Cohen’s Kappa) of two observers. Three different games (SRB-ROM, SRB-GER, SRB-HUN) were selected for this purpose. The Cohen’s Kappa value of the observation model varied between .80 ≤ K ≤ .86, which represents an “excellent” classification (Robson, 2002).

Performance relevance of tactical patterns: Due to the small number of games investigated and to the high variance in the empirical match data of the observed teams in the Water Polo World League Final 2007, no significant differences between the performance relevance of the different tactical behaviour patterns of Germany and Serbia could be found. Nevertheless, the differences reported below at least exhibited a clear tendency (p < 0.10).

The descriptive results showed that the performance relevance of the “Turn over to counter attack” (TO-CA) in general was the most while-tactical positional pattern in the observed international water polo matches. Especially in the German team this specific transition was much more important than in the Serbian and all other teams \( M_{\text{GER}} = 1.39 ± 0.81 \) \( n = 6 \) vs. \( M_{\text{SRB}} = 0.45 ± 0.99 \) \( n = 6 \) resp. \( M_{\text{ALL}} = 0.43 ± 0.14 \) \( n = 15 \). Furthermore, in the winning teams the transition from winning the ball into a winning fast break was much more effective for the losers \( M_{\text{WIN}} = 0.70 ± 1.18 \) \( n = 10 \) vs. \( M_{\text{LOS}} = 0.32 ± 1.70 \) \( n = 7 \). In addition to that, the winning teams also showed a higher effectiveness when turning over the win of the ball into a more static position attack. This can be seen by the transition from “Turn over to center attack” (TO-CPOCA) in general, which was only positive in the winners of the observed games \( M_{\text{WIN}} = 0.32 ± 0.10 \) \( n = 12 \) vs. \( M_{\text{LOS}} = 0.34 ± 1.21 \) \( n = 12 \).

Concerning the position attack itself, the performance relevance of the tactical pattern to pass the ball from the “Back-position in the one-center position attack to the Center-position” (BPOCA-CPOCA) is positive in all teams, but by far highest in the German team \( M_{\text{GER}} = 1.34 ± 0.07 \) \( n = 6 \) vs. \( M_{\text{SRB}} = 0.27 ± 1.34 \) \( n = 6 \). On the other hand, for the winners this kind of center play was much less relevant than for the defeated teams \( M_{\text{WIN}} = 0.60 ± 1.14 \) \( n = 12 \) vs. \( M_{\text{LOS}} = 1.70 ± 3.04 \) \( n = 12 \). Also important in water polo is the tactical manoeuvre from the position attack to the man-up situation, when an opposition player has been excluded from a period of play. So, the transition from ball possession in the “Back-position in the one-center position attack to the man-up attack” (BPOCA-MUA) was also positive in all investigated teams, and again highest in the German team \( M_{\text{GER}} = 1.39 ± 1.58 \) \( n = 6 \) vs. \( M_{\text{SRB}} = 0.49 ± 2.05 \) \( n = 6 \). But as already seen above, this kind of advantage was less relevant for the winners than for the losers \( M_{\text{WIN}} = 0.55 ± 0.74 \) \( n = 12 \) vs. \( M_{\text{LOS}} = 1.86 ± 2.71 \) \( n = 12 \). The reason for the latter two, somewhat surprising findings might result from the fact that the winning teams seem to put more emphasis on playing fast polo, i.e. on counter attacks and also on the pattern of “driving-in” into the area in front of goal. So, the transition from holding the ball in the “back-position to driving-in” (BPOCA-DI) is much more effective in the winning teams than in the losers, where it even had a negative effect on the total score \( M_{\text{WIN}} = 0.20 ± 0.69 \) \( n = 12 \) vs. \( M_{\text{LOS}} = -0.22 ± 1.06 \) \( n = 12 \).

DISCUSSION

In this study, performance diagnosis in water polo by stochastic path simulation was used for the first time. In comparison with traditional notational analysis methods in water polo (Bratusa, Matkovic & Dopsaj, 2003; Dopsaj & Matkovic, 1999; Holmman, 1992; Platanou & Nikolopoulous, 2003), the main advantage of this approach is that it delivers not only a statistical description of the analyzed tactical behaviour, but is also capable of: (a) analyzing the performance relevance of the various tactical behaviour patterns, and (b) providing a prognosis on the probable effects of certain modifications to the tactical behaviour of interest, based on a mathematical simulation of the interactive game process. Performance diagnosis through stochastic path simulation by means of the Markov-chain model, hence, is a worthwhile performance diagnostic procedure in water polo, allowing the calculation of optimal tactical behaviour.

REFERENCES


Training Age and Fitness Levels in a Static Position

Throwing Accuracy of Water Polo Players of Different Training Age and Fitness Levels in a Static Position and after Previous Swimming

Platanou, T. and Botonis, P.

Faculty of Physical Education and Sport Science, University of Athens, Greece

The aim of the present study was to compare throwing accuracy in a static position to after previous swimming in relation to training age and fitness level. Fifty (50) water polo players (aged: 11-17 yrs) were tested. Significant differences were observed in throwing accuracy between the static position and after previous swimming (F=58.05, P<0.001) by training age (F=21.8, P<0.001) and by fitness level (F=44.73, P<0.001). Moreover, throwing accuracy was greater in a static position than after previous swimming. Players with greater training age and better swimming performance had higher throwing accuracy than younger players and those of with lower swimming performance. No significant differences were observed between Δ values in throwing accuracy in a static position or after previous swimming in relation to training age and fitness level.

Keywords: overhead shot, performance, lactate, young water-polo players

INTRODUCTION

Shooting is a technical skill, which is a frequent occurrence in a water polo match. This skill is most frequently overhead throwing. Ninety percent of throwing during water-polo games is overhead throwing (Bloomfield et al. 1990). In water-polo, two possibilities for shooting are given, shots that are made when the player is in a static position or after previous swimming. In the first case, these are shots made while the player is in the periphery of the rival region swimming in a vertical position for a period of time and receives a pass from another player. In the second case, the shot is made after swimming during the pick play and the player is relatively tired. Training improves physical and technical skills, which are two basic components of fitness. Two of the most basic elements of water polo are firstly, swimming speed, which gives the possibility for fast and continuous movement in a water-polo game and secondly, throwing accuracy.

The effectiveness of the shot mostly depends on accuracy. Daily training includes drills in order to improve scoring efficiency. In addition, swimming efficiency may contribute to effectiveness of throwing as players with efficient swimming technique have less fatigue. Lactic acid, is one of the main factors that affects muscle contracting capabilities and possibly neuromuscular coordination. A high lactate concentration in the blood likely has negative consequences in throwing accuracy and is related to the intensity of exercise. In water-polo, there are few studies that investigated the biomechanics and the speed of throwing accuracy (Triplett 1991, Feltner 1996 Bloomfield et al. 1990). However, to our knowledge there are no studies investigating the effect of training age and fitness level on throwing accuracy in a static position or after previous swimming. Therefore, the aim of this study was to compare the accuracy of shooting, static or with previous swimming, in relation to a) training age and b) fitness level. It was hypothesized that shots in a static position would be more accurate than after previous swimming and that water-polo players of greater training age and those of greater swimming performance would be more accurate compared with inexperienced water-polo players, or of lower fitness level.

METHODS:

Fifty players (aged:11-17 years) were tested in shooting accuracy in a static position and after previous swimming and divided into 3 groups according to a) training age based on the number of training years (14 players with 2-3 years of training age, 22 players of 4-5 years of training age and 14 players of 6-8 years training age) and b) fitness level based on the results of the Greek championship at its corresponding age (15 players with 60- 40 s in 50 m, 17 players with 39.90-32.00 s, and 18 with less than 31.90 s). The experimental procedure lasted for 3 days. In the first day, the swimming performance for 50m of each participant was measured. The day after, the shooting skill test was conducted. The test required participants to perform either five shots in static position or five shots after previous swimming in a random and counterbalanced order. In particular, each individual executed 5 shots at a pre-designated target, from a constant place after previous sprint swimming from 10 m to 5m from the goalpost. After the shot, each participant returned to 10m, and after a 15 s interval, made the next shot (Figure 1). On the third day, players performed 5 more shots after swimming 10m away from the goalpost and stopped in 5m for shooting. This time the participants started swimming with the ball from the 10m to 5m distance with no interval time between shots, and then returned back at 10m took another ball, swam to 5m in order to execute the next shot. Targets had been placed at 2 corners of the goalpost with dimensions being double size of ball’s diameter (Figure 2). Blood samples for lactate concentration measurement were taken at 1, 3 and 5 minute of recovery from fingertip (Accusport, Boehringer, Germany).

RESULTS

Significant differences were observed between shooting conditions (F=58.05, P<0.0001). The accuracy of shots from a static position were significantly better than shots after previous swimming (2.8 ±1.3 vs 1.7 ±1.1, respectively). Additionally, significant differences were found between groups of different training age. In particular, water-polo players with greater training experience had higher throwing accuracy, both in a static position or after previous swimming (Table 1). Moreover, fitness level, according to the swimming performance test of 50 m, affects the throwing accuracy (Table 2). Specifically, subjects with a higher fitness level had greater throwing accuracy (F=44.73 p<0.0001). No significant differences were observed between Δ values in throwing accuracy in a static position or after previous swimming in relation to training age and fitness level.
Shooting after previous swimming is a complicated technique, that consists of swimming, shooting and the transition from a horizontal to a vertical position. Each part of a complicated technique should be

### Table 1. Throwing accuracy in a static position and after swimming in relation to training age

<table>
<thead>
<tr>
<th>Variables</th>
<th>First group (2-3 years)</th>
<th>Second group (4-5 years)</th>
<th>Third group (6-8 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static accuracy</td>
<td>1.7±0.9*</td>
<td>2.7 ± 1.3**</td>
<td>4.0 ± 0.7***</td>
</tr>
<tr>
<td>Static accuracy (%)</td>
<td>35.0±13.9*</td>
<td>53.8±22.4*</td>
<td>80.0±14.7***</td>
</tr>
<tr>
<td>Accuracy pr. swimming</td>
<td>0.6 ± 0.5*</td>
<td>1.7 ± 1.0**</td>
<td>2.7 ± 0.8***</td>
</tr>
<tr>
<td>Accuracy pr. swimming (%)</td>
<td>11.7±9.3*</td>
<td>34.6±20.0*</td>
<td>53.3±15.6**</td>
</tr>
<tr>
<td>Difference accuracy</td>
<td>1.2 ± 1.0</td>
<td>1.0 ± 0.9</td>
<td>1.3 ± 0.9</td>
</tr>
<tr>
<td>Difference accuracy (%)</td>
<td>23.3±20.6</td>
<td>19.2±19.0</td>
<td>26.7±19.7</td>
</tr>
</tbody>
</table>

(*) significant difference between the first and second group, (**) significant difference between the second and the third group, (*** ) significant difference between the first and the third group (P<0.05).

### Table 2. Accuracy results of 3 age groups, static and with previous swimming in relation to performance in 50m free swimming.

<table>
<thead>
<tr>
<th>Variables</th>
<th>First group (6-10 years)</th>
<th>Second group (11-15 years)</th>
<th>Third group (16-20 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static accuracy</td>
<td>1.6±0.8*</td>
<td>2.7±1.1**</td>
<td>3.8±0.7***</td>
</tr>
<tr>
<td>Static accuracy (%)</td>
<td>32.0±16.6*</td>
<td>54.1±22.1**</td>
<td>76.7±14.1***</td>
</tr>
<tr>
<td>Accuracy pr. swimming</td>
<td>0.5±0.7*</td>
<td>1.6±0.8**</td>
<td>2.7±0.8**</td>
</tr>
<tr>
<td>Accuracy pr. swimming (%)</td>
<td>10.3±14.9*</td>
<td>32.9±15.7**</td>
<td>53.3±15.3**</td>
</tr>
<tr>
<td>Difference accuracy</td>
<td>1.1±0.9</td>
<td>1.1±1.1</td>
<td>1.2±1.0</td>
</tr>
<tr>
<td>Difference accuracy (%)</td>
<td>21.3±19.2</td>
<td>21.2±21.1</td>
<td>23.3±19.7</td>
</tr>
</tbody>
</table>

(* ) significant difference between 1st and 2nd group, (**) significant difference between 2nd and 3rd group, (***) significant difference between 1st and 3rd group, (P<0.05)

Regardless of group, the blood lactate concentration was significantly lower when shooting in a static position than after previous swimming (4.58±0.49 vs 3.20±0.50 mmol/L, P<0.0001, respectively). However, no significant differences were observed in blood lactate concentration in relation to training age or fitness level. The three groups of different training age and fitness level were similarly affected regarding accuracy in a static position or after previous swimming.

Water-polo is a team sport, in which accuracy is the main goal i.e. shooting effectiveness. This effectiveness is related to many factors such as shot velocity, shooting time and accuracy. In this study, overhead throwing accuracy was investigated because it is one of the main factors that determines shooting effectiveness. The subjects shot at the rival goalpost in a vertical position waiting for the ball or after previous swimming with the ball for a 5m distance and immediate shot. Our results showed that the shooting accuracy in a static position after rest is more accurate than shooting after previous swimming. This is attributed to the possible perturbation of neuromuscular coordination, in shooting after previous swimming. Furthermore, one possible explanation is that the shooting technique and the neuromuscular coordination might be disturbed by the significantly higher blood lactate concentration found in shooting after previous swimming. It seems that the level of lactate concentration shows the level of exertion. In the present study, the higher blood lactate concentration in shooting after previous swimming than in shooting in a static position shows that the effort level was higher in shooting after previous swimming. Similar results were found by Royal and colleagues (2009). In that study, the lactate accumulation was related to the exertion level. In the present study, blood lactate values were not very high showing that the higher blood lactate concentration in shooting after previous swimming (4.58±0.49 vs 3.20±0.50) had negative effect on shooting accuracy. During intense short movements, players mainly consume anaerobic lactate energy, whereas during their less intense movements, they consume aerobic energy. The main result of this study is that accuracy is significantly lower in shooting after previous swimming. It is suggested that fatigue may have been occurred in shooting after previous swimming and affected accuracy. Our results are consistent with the findings of Erquli and Supej, (2009). These researchers found that fatigue accumulation is an important factor, which determines shooting accuracy and performance in elite basketball players and that shooting effectiveness decreases with increasing fatigue. However, the research protocol was different than ours allowing higher lactate concentration values (around 10 mmol/L).

Accuracy is an ability that can be improved with repetition. Consequently, the training time is an important factor for improving the ability of throwing accuracy. In this study, the water-polo players of higher training age had greater throwing accuracy in both absolute values and in percentage (%) values than less experienced players. Moreover, it seems that this parameter is a significant predictor of shooting accuracy. The blood lactate concentration was similar between groups. Moreover, it was observed that the difference in shooting accuracy between shooting in a static position and after previous swimming was similar in relation to training age. In addition to that, accuracy and neuromuscular coordination were similarly affected by fatigue and lactate concentration, when shooting was made after previous swimming. As a result, there was no difference in accuracy in a static position or after previous swimming as Δ values, relatively to training age.
correctly executed, in order for the whole to be effective. It is possible that inefficient swimming technique has a negative effect on shooting accuracy. Effective swimming technique is one of the main factors that determines swimming performance in a given distance. One other main factor is the fitness level. In the present study, the participants of higher swimming performance had greater shooting accuracy than participants with lower swimming performance. According to our results, it was revealed that fitness level is a significant predictor of accuracy either in shooting in a static position or after previous swimming. However, Δ values in accuracy between shot in a static position and after previous swimming were not different in relation to fitness level.

Significantly high correlation was observed in swimming performance and training age. Moreover, training age and swimming performance were significantly correlated with shooting accuracy either in a static position or after previous swimming. It seems that yearly training improves shooting accuracy. The swimming performance, also, which can be considered not only as a fitness level index but as an index of adequate swimming technique, strongly affects shooting accuracy. According to our findings, our hypothesis that shots in a static position would be more accurate than after previous swimming and that water-polo players of greater training age and those with better swimming performance would be more accurate compared with inexperienced water-polo players, of lower fitness level, was verified.

CONCLUSION
The present study is the first to investigate shooting accuracy in a static position and after previous swimming of water-polo players differing in training age and swimming performance. These results suggest that shots in a static position are more accurate than shots after previous swimming. Additionally, shooting accuracy is highly dependent on training age. The inexperienced water-polo players were less accurate than players of greater training age. According to our results, it seems that shooting accuracy is highly dependent on swimming performance. The water-polo players of lower swimming performance had a significantly lower percentage of accurate shots than players of greater swimming performance. There is no difference in accuracy between shot in a static position and after previous swimming as Δ values, in relation to training age or swimming performance. Previous swimming has a negative effect on shooting accuracy, regardless of the training age. The data of this study should be applied to athletes of similar level and could provide water polo coaches with guidelines for training.

REFERENCES

The Effect of Cognition-Based Technique Training on Stroke Length in Age-Group Swimmers

Schmidt, A.C.1, Ungerechts, B.E.2, Buss, W.3 & Schack, T.4
1University of Göttingen, Department of Society and Training, Germany
2University of Bielefeld, Department of Neurocognition and Action – Biomechanics, Germany

This study deals with a specific and innovative aspect of long-term performance-planning in swimming: cognition-based technique training. Based on the studies of Thomas Schack on the cognitive architecture of movements, the cognition-based technique training method was developed and proved the first time in swimming. The study applies the program ‘Split’, which has already been successfully used in other sports. Split uses distance scaling between the elements of a system of concepts to measure conceptual structures. To evaluate the potential introduction of cognition-based technique training in long-term performance-planning of swimmers, biomechanical criteria were used.

Key words: age-group swimmers, crawl, representational structure, stroke distance, stroke rate

INTRODUCTION
Highly skilled swimmers aspire to cover as much distance per stroke as possible. According to Reischle (1988) and Azellano et al. (1991) an improved swimming technique results in a longer stroke length. Therefore it is likely that the athlete swims the same race-distance with fewer strokes and probably in less time. In the case of less time and increased stroke length, the so-called stroke-index (speed squared and multiplied by stroke length) will also be increased.

Knowing this, it is obviously important to increase the stroke length of any swimmer. To gain more effective underwater-movement, the swimmer could increase his power (without technical training this might be limited soon) and / or try to optimize his motion sequence in relationship to the water. In contrast to most other sporting activities, swimmers do not have a fixed base to push off. Swimmers, instead, produce propulsion due to interaction of body and water-mass. Therefore it is very important to educate swimmers at the beginning of long term performance planning on how to work with water properly while executing regular strokes. To reach this, emphasis should be placed on how stroking is mentally represented by swimmers, even age-group swimmers.

Advanced age-group swimmers, in order to improve the efficacy of their stroking actions, have to control the stroke-technique mentally as a prerequisite to optimize details of motion sequences. In this context a cognitive intervention can be used which is based on the Structural Dimension Analysis of Motor Memory (SDA-M) according to Schack (2003). Ungerechts/Schack (2006) did a first study of the representation of butterfly-swimmers using SDA-M and described the method.

SDA-M is used to describe mental representation structures and it enables statements about the cognitive architecture of complex movements in the long-term memory. This means, interpreting the results, one can understand how the swimmer is thinking about his movements, which parts (nodes) he connects closely and where there are large distances or connections, which – biomechanically – are not reasonable. So the major cause of problems of (stroking) actions can be localized in a way which fits with the demand of effective communication between coach and athlete. The purpose of this paper is to examine the effect of cognition-based technique training on the stroking ability of age-group swimmers.
METHOD
The empirical study was carried out on three test days. A test group and a control group with 23 and 24 age-group swimmers, respectively, were involved in the study. Between the first and second test day the test group performed specific workouts for six weeks. On the test days the program 'Split' (SCHACK et al., 2000) was used to evaluate the representational structure and the swimmers also performed a swimming test of 2 x 25 meters crawl stroke at full speed. The control group only performed the swimming test. To evaluate the long-term educational effects of the cognition-based training, the swimmers of both groups trained for another 12 weeks. The study was concluded by a final swimming test for both groups and the test group also used 'Split' again.

During the sprints on the test days a) the time over a 10m distance – from 10 to 20 m – and b) the stroke rate were measured and finally the stroke length and the stroke index were calculated (the data of the two trials were averaged). “Split” was used to sort out “basic action concepts”, called nodes, representing arm/hand actions during crawl stroke. The nodes were established by the coach in close relation to how he/she normally describes stroking, however in a more structured manner.

After sorting out all nodes according to the criteria, if they belong to the anchor node or not, as result one gets an impression of the mental representation, which the swimmer has of its motion sequence (in this example of the crawl arm stroke). By means of this computer programme, the so-called split technique is used in order to achieve the data of proximity.

“The SDA-M consists of four steps: First, a special split procedure involving a multiple sorting task delivers a distance scaling between the BACs of a suitably predetermined set. Second, a hierarchical cluster analysis is used to transform the set of BACs into a hierarchical structure. Third, a factor analysis reveals the dimensions in this structured set of BACs, and fourth, the cluster solutions are tested for non-variance within- and between-groups (for psychometric details, see Schack, 2001, 2002” (BLÄSING et al. 2009).

The mental representation is described by a so-called dendrogram and clusters (groups of individual nodes). Analyzing the dendrograms and the clusters special training-programs were created (theoretical and practical), which were performed during the six week training period. The individual stroking instructions were inferred from the results of the SDA-M tests. The communication between coach and athlete was based on defined notes. During the workouts established drills were used in another context, dealing with one or more BAC and their connection to each other. First the coach explained to the athlete (a) the results of split and in most of the cases (b) again all the nodes and their impact in the stroking action, especially the ‘problem-nodes’ of the athlete. This was the basis of the workouts covering each node with drills and then later on groups of nodes and especially the ‘problem’ nodes. So in each workout (after one or more drills) by using the nodes, the connection of one node to the neighbor-nodes or a group of nodes to each other was discussed. During stroking the swimmer had to concentrate on what he was doing and on his feelings (e.g. stroking, propulsion) telling this later to his coach.

As an example, the BACs of one of the training groups are shown here:

Fingers enter water (1), Shrugging shoulders (2), Rolling to side of action (3), Downwards (4), Pronation (5), Elbow extension (6), Rolling back (7), Slicing hand (8), Breathing (9), Hand forward (10).

RESULTS
The following figures show the representational structure of one swimmer at test 1, 2 and 3.

Fig. 2 Dendrogram of one swimmer (test 1) without any cluster and without a real regularity of the nodes. The distances between the nodes are quite large, therefore do not cluster.

Fig. 3 Dendrogram of the same swimmer after the six week training period (test 2) with three clusters (all nodes are integrated in clusters and are in biomechanical regularity)

Fig. 4 Dendrogram of the same swimmer after 18 weeks (six weeks specific training and 12 weeks ‘normal’ training (data 3). The dendrogram shows four clusters, regularity of nodes, but also partly increased distances between nodes.

At test 1 the structure is not really sorted, the distances between the BACs are quite large (it does not have any clusters). After the training period
(test 2), however, all BACs are integrated in clusters, the distances are smaller and the nodes are in regularity. After the twelve weeks training period (test 3) the structure is quite stabilized, some distances are once again reduced (p. E. 9 and 10, 5 and 6) but also some (p. e. 3 and 4, 7 and 8) increased.

The following schedule shows a way to transfer the structure of the dendrograms above into a schedule to compare it directly. Each dendrogram shows 2 main groups, but only test 2 and (3) shows 3 and 4 clusters. At test 2 there are 6 nodes (2 clusters) in the main group 1, at test (3) 7 nodes (3 clusters). According to main group 1 are in main group 2 at test (2) 4 nodes (1 cluster) and at test (3) 3 nodes (1 cluster). The real distances between the single nodes cannot be shown in the schedule, these details are only visible directly in the dendrograms.

Tab. 3 Statistical data for test group

<table>
<thead>
<tr>
<th>Test</th>
<th>Number of main groups</th>
<th>Number of Cluster</th>
<th>BAC main group 1</th>
<th>BAC main group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>2</td>
<td>0</td>
<td>1,2,4</td>
<td>5,8,9,10,7,3</td>
</tr>
<tr>
<td>Test 2</td>
<td>2</td>
<td>3</td>
<td>(9,10)</td>
<td>(1,2,3,4)</td>
</tr>
<tr>
<td>Test 3</td>
<td>2</td>
<td>4</td>
<td>(8,9,10)</td>
<td>(1,2,3,4)</td>
</tr>
</tbody>
</table>

The improvement in mental representation shown as example for one swimmer above also led to improvements in the swimming parameters (also shown for one swimmer below). According to Reischle (1988) and Arellano et al. (1991) the following parameters were selected to demonstrate technical progress: first, stroke length and second, stroke index which combines stroke length and swimming speed.

The following schedule lists the time (10 metres) (t), speed (v), stroke rate (sr), length (d) and the stroke index (si) of the example swimmer.

Tab. 2 Biomechanical data of one swimmer at test (1), (2) and (3)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test 1 (mean, std)</th>
<th>Test 2 (mean, std)</th>
<th>Test 3 (mean, std)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>1.53 ± 0.09 m/s</td>
<td>1.52 ± 0.11 m/s</td>
<td>1.49 ± 0.09 m/s</td>
</tr>
<tr>
<td>Stroke rate</td>
<td>49.61 ± 4.2 min</td>
<td>47.81 ± 3.26 min</td>
<td>46.70 ± 4.18/min</td>
</tr>
<tr>
<td>Stroke length</td>
<td>1.85 ± 0.16 m</td>
<td>1.92 ± 0.19 m</td>
<td>1.93 ± 0.20 m</td>
</tr>
<tr>
<td>Stroke index</td>
<td>4.36 ± 0.72</td>
<td>4.50 ± 1.01</td>
<td>4.34 ± 0.80</td>
</tr>
</tbody>
</table>

The speed remained nearly the same over the 3 tests. Comparing the stroke length, however, an increase of approx. 0.07 m (60 strokes = 4.20 m) and again 1 cm to test (3). The stroke rate decreased by approx. 2 and 1 strokes per minute. The stroke index increased from test 1 to test 2 and decreased to test 3. Although there are small increases, only the stroke rate changed significantly (shown by the Wilcoxon signed-rank test).

The following table shows the mean data of relevant parameters (test 1, 2 and 3) of the test group.

Tab. 3 Statistical data for test group

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test 1 (mean, std)</th>
<th>Test 2 (mean, std)</th>
<th>Test 3 (mean, std)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>1.38 ± 0.10 m/s</td>
<td>1.30 ± 0.11 m/s</td>
<td>1.28 ± 0.08 m/s</td>
</tr>
<tr>
<td>Stroke rate</td>
<td>49.63 ± 3.62 min</td>
<td>48.65 ± 3.87/min</td>
<td>48.80 ± 4.62/min</td>
</tr>
<tr>
<td>Stroke length</td>
<td>1.68 ± 0.15 m</td>
<td>1.62 ± 0.16 m</td>
<td>1.57 ± 0.18 m</td>
</tr>
<tr>
<td>Stroke index</td>
<td>3.23 ± 0.66</td>
<td>2.81 ± 0.70</td>
<td>2.60 ± 0.56</td>
</tr>
</tbody>
</table>

In contrast with the test group, the control group does not show any increases. Rather the speed and the stroke distance decreased, while the stroke rate nearly remained at the same level.

DISCUSSION
Comparing the test-group-results of the three tests after six weeks training including a SDA-M based intervention the increase of stroke length at a similar speed is obvious. This can also be shown for the stroke index (test 1 to 2, which is based on speed and the stroke length. Longer stroke length is an indicator of an increased effect of the stroking action. In combination with lower stroke rate a total increase of efficiency is obvious. However, without the specific workouts the test group also could not stabilize the high level reached at test 2. The chosen parameters also decreased a bit, but reached at test 3 a level between test 1 and test 2.

In contrast of the test group, the control group remained on the level of test 1 or the results decreased. Without using Split or doing the specific technique training, they did not show the same changes as the test group.

Even though the changes were mostly not statistically significant, the intervention made an impact: the participating swimmers increased their cognitive ability and thus enhanced their own power to optimize their aquatic space activities. But this seems to be a first, small step – without the specific training the changes could not be stabilized at the high level of test 2. Either the intervention-time was too short or it might be important to repeat the specific workouts for better stabilization. Presumably, if the SDA-M based stroking instructions causes large-sale changes, the concerned swimmers were not able to automate the new motion sequence in the short time of the intervention. Especially when they try to swim at maximal speed, they did not manage to continuously produce the motion sequence at an optimized level or they did not reach maximal speed, they swam more slowly than on the pre-test.

CONCLUSION
The elected method stands the test, although it will be important in the future to study again this type of training in the domain of motor control and motor learning, for example during a longer intervention. In the future, technique training offers great potential for more effective training of age-group swimmers. In long term performance planning, more time should therefore be spent on the education of motor competence starting early in the swimmer's education. With advanced swimmers the cognition based technique training can be used to work systematically on the cognitive representation of the motion in theory and practice. However, this requires better education of the swimmers in the theoretical background of the different strokes.

REFERENCES
Assessing Mental Workload at Maximal Intensity in Swimming Using the NASA-TLX Questionnaire

Schnitzler, C.*, Seifert, L.*, Chollet, D.*

* CETAPS EA 3832, Faculty of Sports Sciences, University of Rouen, France

The sensitivity of the NASA-TLX questionnaire to gender, age and expertise was investigated. Fifty subjects performed a 400-m front crawl at maximal velocity. Then, 100-, 200- and 300-m trials at the same velocity were performed. Mental workload was assessed. The results showed that total subjective workload (TWL) increased gradually with the distance (p<.05). Women and adults exhibited higher TWL at the end of the 400-m test (p<.05), but no significant difference was noted for the expertise effect. A six-month re-test showed no significant change in TWL for swimmers with the same performance or for those with significant improvement. The NASA-TLX questionnaire may thus be a useful tool to assess the dimensions of subjective assessment of complex tasks in sports like swimming.

Keywords: Gender, age, expertise, maximal aerobic speed

INTRODUCTION

The perception of effort, according to Borg (1998), should be considered a configuration of sensations, particularly regarding the magnitude of effort being processed. The rate of perceived exertion (RPE) is a valuable tool for monitoring relative training intensity and has been widely used to investigate the link between perception and physiological parameters, especially regarding the impact of training programs (Borg, 1998). Newell (1986), however, showed that the energetic requirement of the task is only part of the task difficulty, for biomechanical, morphological and environmental constraints are interacting components in task complexity. Mental workload, considered as the relationship between resource supply and task demand (Wickens, 1992), may be a useful approach to investigating this complexity. Hart and Staveland (1988) validated the Task-Load Index Questionnaire (NASA-TLX), which divides the perceptual assessment of a given task into six independent dimensions. This questionnaire appears of interest for complex activities in which large numbers of components interact for final performance, but it has also been used to investigate tasks which require only low energetic involvement (Reid & Nygren, 1988).

The subjective assessment of a swimming performance is generally based on the intensity of effort, using simple scales like the RPE, although many other dimensions are involved, like technical efficiency (Toussaint & Truijens, 2005) and race management (Schnitzler et al., 2007). By limiting assessment to the RPE, other dimensions that could provide useful information on task difficulty might therefore be overlooked. On the other hand, the sensitivity of NASA-TLX in tasks close to maximal intensity has not been evaluated, nor has the variation in responses as a function of population characteristics. Thus, the aim of this study was to investigate the variation in the total subjective workload (TWL) of swim trials swum at the velocity of a maximal 400-m front crawl test as a function of distance swum, age, gender and expertise.

METHODS

Fifty subjects (27 men, 23 women), volunteered to participate in the experiment. The protocol was fully explained to the subjects and all provided written consent to participate in the study, which was approved by the university ethics committee. They were divided into expert and recreational populations. The experts were highly trained competitors of national and international level, training 20±1.5 hour/week. These experts were further subdivided into adult and youth populations. The recreational swimmers were students from the Sports Sciences University and trained 1.5±2 hour/week. The main characteristics of all subjects are presented in Table 1.

Table 1. Characteristics of the populations

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Number</th>
<th>Highly trained</th>
<th>Recreational</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td>Men</td>
<td>Women</td>
<td>Adult</td>
</tr>
<tr>
<td>15±1.3</td>
<td>20±0.1</td>
<td>15±3.1</td>
<td>20±0.2</td>
</tr>
<tr>
<td>20±1.3</td>
<td>38±17</td>
<td>37±20</td>
<td>70±25</td>
</tr>
<tr>
<td>25±1.3</td>
<td>47±22</td>
<td>49±18</td>
<td>70±25</td>
</tr>
<tr>
<td>30±1.3</td>
<td>48±22</td>
<td>52±20</td>
<td>70±25</td>
</tr>
<tr>
<td>35±1.3</td>
<td>59±13</td>
<td>70±21</td>
<td>64±21</td>
</tr>
</tbody>
</table>

Own performance 46±22 52±28 47±25 51±25 50±28 48±19
Temporal demand 47±22 49±18 36±20 57±20 48±22 48±17
Effort 59±13 70±21 64±16 65±20 64±21 66±12

Part (i): A four-way ANOVA tested the population’s response after the all-out 400-m (fixed factors: expertise, gender, age; random factor: subject) on peak [La-], TWL and its six dimensions.

Part (ii): A two-way ANOVA tested the expert population (gender (2 levels: men, women); repeated factor: distance swum (4 levels: 100-m, 200-m, 300-m, 400-m); random factor: subject (12 levels)) on [La-], HR, and TWL and its six dimensions. The Pearson coefficient of correlation was calculated between physiological and psychometric parameters.

Part (iii): Expert swimmers were tested using ANOVA for pair-wise data (repeated factor: time of the test (2 levels: trial 1, trial 2)) on V<sub>BPM</sub>, [La-], and TWL and its six items. The Tukey post-hoc test was used to locate the differences. The significant-difference level was set at p<.05.

RESULTS

Part (i): Significant differences among dimension scores of the NASA-TLX were found after the 400-m. The “effort” and “physical demand” items of the task were not significantly different and both were scored significantly higher than the other dimensions (p<.05). The differences among the other dimensions were not significant. Significant differences were observed for gender, age and expertise on [La-], TWL and the dimensions of the questionnaire. (Table 2). No interaction was found between any of the parameters tested.
Part (ii): Table 3 presents the results for the highly trained population that performed 100-m, 200-m and 300-m trials at the speed of the previous 400-m.

Table 3. Distance effect on physiological and NASA-TLX (highly-trained population)

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>HR (Bpm)</th>
<th>[La-] (mmol/l)</th>
<th>TWL (100)</th>
<th>Mental demand</th>
<th>Physical demand</th>
<th>Temporal demand</th>
<th>Own performance</th>
<th>Frustration</th>
<th>Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>168±10.7</td>
<td>3.5±0.6a</td>
<td>32±29c,d</td>
<td>24±28</td>
<td>21±22</td>
<td>37±20</td>
<td>55±37</td>
<td>27±28</td>
<td>32±16c,d</td>
</tr>
<tr>
<td>200</td>
<td>176±7.8</td>
<td>6.4±0.9c,d</td>
<td>39±24</td>
<td>31±23</td>
<td>37±13</td>
<td>60±27</td>
<td>32±24</td>
<td>47±20</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>180±4.3</td>
<td>7.8±1.6c</td>
<td>49±24</td>
<td>40±21</td>
<td>56±28</td>
<td>63±25</td>
<td>61±25</td>
<td>52±21</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>166±17.2</td>
<td>10.4±1.8c,d</td>
<td>50±28</td>
<td>33±21</td>
<td>65±29</td>
<td>46±28</td>
<td>53±13</td>
<td>34±28</td>
<td>63±19</td>
</tr>
</tbody>
</table>

* Significant change with distance swum, with p<0.05

The repeated-three way ANOVAs showed significant improvement in TWL, "physical demand", and "effort", with p<0.05 (see Table 3). The Tukey post-hoc test indicated a difference only between the 100- and 300-m trials and the 100- and 400-m trials. Significant increases in HR and [La-] were nevertheless recorded. The correlation coefficients between TWL and the physiological parameters were significant (r = .46, p<.05 between TWL and HR and r = .38, p<.05 between TWL and Hla).

Part (iii): After three months of training, eight swimmers were retested. Their results are presented in Table 4.

Table 4. NASA-TLX retest scores at retraining with significant improvement in performance

<table>
<thead>
<tr>
<th>Period</th>
<th>HR (BPM)</th>
<th>[La-] (mmol/l)</th>
<th>TWL/ 100</th>
<th>Mental demand</th>
<th>Physical demand</th>
<th>Temporal demand</th>
<th>Own performance</th>
<th>Frustration</th>
<th>Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>188±9.2</td>
<td>8.5±1.6</td>
<td>48±7</td>
<td>31±24</td>
<td>57±14</td>
<td>40±23</td>
<td>64±22</td>
<td>50±25</td>
<td>46±25</td>
</tr>
<tr>
<td>Trial 2</td>
<td>181±7.4</td>
<td>10.7±1.5</td>
<td>48±5</td>
<td>34±15</td>
<td>56±19</td>
<td>49±18</td>
<td>35±19</td>
<td>30±15</td>
<td>64±16</td>
</tr>
</tbody>
</table>

* Significant change with p<.05

No significant difference in TWL was noted for either group. However, "own performance" and "frustration" significantly decreased (p<0.05), whereas "effort" significantly increased (p<.05) in the group who improved their swimming speed. No interactions between gender and retest were noted for any of these parameters.

DISCUSSION

The aim of this study was to analyze the responses to the NASA-TLX questionnaire in different populations after swim trials of variable relative intensities and comparing different periods.

Part (i): After a maximal 400-m, the TWL dimensions of "physical demand" of the task and "effort" exhibited significantly higher values than the other four dimensions. This result is consistent with the current literature, for such effort involving VO2max (Schnitzler et al., 2007) is associated with a high level of perceived exertion. However, the value of TWL, around 50/100, might appear quite low with regard to the difficulty of the task. But this task, which is low in uncertainty, involves mostly automated coordination, and therefore requires more energetic than cognitive skill, with the exception of the management of energetic resources. This might lower the TWL score, which here was an average of all four cognitive dimensions. However, the "physical demand of the task" and "effort" dimensions were scored much higher (56-70/100), comparable to the results reported by Borg for the CR10 scale for effort of similar magnitude (Borg, 1998).

One important assumption in psychophysics is that the perception of intensity is approximately the same for everyone at maximal exertion (Borg, 1998). In this sense, the magnitude of TWL after a maximal 400-m swim should not vary significantly among populations. However, as the NASA-TLX includes other dimensions aside from those related to the perception of physical difficulty, the potential differences between populations were of interest.

First, our results showed that women had significantly lower TWL than men. A closer look at the individual dimensions of the tasks showed that only "effort" was judged lower by women. This result is in line with Kolyn et al. (1991), who found that women assessed a VO2max determination test as less strenuous than men. Interestingly, women also exhibited lower [La-] peak, probably due to their lower anaerobic capacity (Medbo et al., 1988). These results suggest that the objective demand of the task (Newell, 1986) is judged similarly by men and women, whereas inner perceptions about the task differ.

Our study also outlined differences between age groups, for young swimmers had lower TWL values than adults. But in this case, only the "temporal demand" of the task differed between populations. This was an unexpected result, since this parameter, which is linked explicitly with race management, is critical in optimizing energetic efficiency in tests based on a self-selected speed (Craig et al., 1985). This suggests that young swimmers perhaps pay less attention to race management than adults, but this conclusion would need further investigation to be confirmed. Again, significant differences in peak [La-] were recorded, in line with Naughton et al. (2000), who showed that the anaerobic metabolic pathways are not fully developed until adulthood.

Comparisons between recreational and expert swimmers showed no difference in [La-] peak at the end of the 400-m trial. In line with Schnitzler et al. (2007), this indicates that despite a significant difference in performance level, the metabolic stress seemed to be comparable in these two populations, thus allowing comparison of TWL. In accordance with our hypothesis, our results showed no difference in TWL between these populations, which indicates that the test results are not influenced by the performance level of the subjects. Interestingly, greater levels of frustration were recorded in the recreational swimmers. Perhaps a lack of technical skill would explain this difference but, again, further investigations are needed to conclude this point.

Part (ii): Taken together, these results outline interesting differences among populations. But is the TLX questionnaire sensitive to the magnitude of the effort? To answer this question, task duration was manipulated. Past studies showed that both physiological and perceptual aspects of a task are sensitive to its duration (Garcin & Billat, 2001), which is why 100-, 200- and 300-m trials were added to the velocity of the initial 400-m. Here, [La-] increased significantly with the distance swum, as did TWL, this result being explained by the increase in both "physical demand" and "effort". Subjective assessment thus appears to be sensitive to the actual energetic requirement of the task, in line with our hypothesis.

Part (iii): Last, it was wondered how training would affect responses to the questionnaire. Eight swimmers of our expert group were thus tested three months after the initial experiment. Indeed, Borg (1998) showed perceived exertion remaining stable despite improved performances due to training. Our results support those conclusions, for TWL, as well as HR and [La-], did not exhibit significant changes. But a closer look at the results showed that the dimensions of the test changed, for "own performance" and "frustration" decreased significantly, whereas "effort" increased significantly. One interpretation is that this group was able to increase their energy expenditure because of their training, which may have led to the higher subjective evaluation of effort. "Effort" thus seems to be linked to an internal sensation configuration, or a gestalt. The same conclusion may apply to "own performance". The lower value assigned to this dimension despite improved performances could be the consequence of a better knowledge of one's potential. Indeed, this group of athletes regularly participated in competitive events and the motivation of competition generally ensures that higher speeds are reached than during training. No recent performance reference was available during the first test for...
these subjects since testing occurred at the beginning of re-training. After three months of intensive training, however, these athletes were probably able to accurately estimate the gap between their current best competitive performance and that of the present experiment. More surprising, then, is the lower “frustration” level found in the second test. This is only speculative, but it may have been because these athletes knew what they were capable of in competitive situations at that time and did not worry that their performance in the experimental conditions was far from what they did in competition.

Finally, it is interesting to note that in the different experimental conditions, a difference in TWL was accompanied by an increase in [La-] level in the comparisons of gender, age and distance swum. But whether these changes were concomitant or the lactate increase was the consequence of the change in TWL goes beyond the scope of this article.

CONCLUSION
The multi-dimensionality of the NASA-TLX questionnaire provides an insight into sport performance. It might be a useful tool to determine the characteristics of specific populations or to monitor change due to training with more precision.

REFERENCES

Does the Y-Intercept of a Regression Line in the Critical Velocity Concept Represent the Index for Evaluating Anaerobic Capacity?

Shimoyama, Y., Okita, K., Baba, Y., Sato, D.

The purpose of the present study was to investigate whether the y-intercept of a regression line in the critical velocity concept could be utilized as an index for evaluating anaerobic capacity. Twenty-one well-trained college swimmers performed a maximum effort swim over 50, 100, 200 and 400m for modeling the distance-time (D-T) relationship and measuring peak blood lactate concentration ([La-]), and a 30-s all-out Wingate Anaerobic Test (WAnT) performed with arms and legs. The y-intercept was significantly related to highest [La], the mean and the peak power of the WAnT performed with both arms and legs. These results suggest that the y-intercept is a valuable index for evaluating anaerobic capacity using a non-invasive method in competitive swimming.

Key words: critical velocity concept, anaerobic capacity, y-intercept

INTRODUCTION
The accurate monitoring of both aerobic and anaerobic capacities is required to make a training program effective (Maglischo 2003). Therefore, several testing procedures have been presented in the literature to measure [La] at sub-maximum intensities and VO2max (Bosquet et al. 2002) for evaluating the aerobic capacity, and to measure the highest [La] (Lacour et al. 1990) and the maximal oxygen deficit (Ogita et al. 1996) for the anaerobic capacity. However, it is difficult to measure these indices in the field, because they rely on the use of expensive equipment and their method are invasive.

A linear relationship is observed between the total work performed during an exhaustive maximal test and the time to exhaustion. In the 2-parameter model, the slope of the linear regression line has been referred to as critical power (Monod and Scherrer 1965), which was defined as the theoretical maximum power that could be maintained without exhaustion for a long time. This critical power concept was applied by Wakayoshi (1992) in swimming (the critical swimming velocity concept). Wakayoshi et al. (1992) suggested that the slope of the linear regression line between distance (D) and time required to cover it (T) at maximal speed could be a critical velocity (CV). Further, there was a positive correlation between the CV and 30-minute maximum swimming velocity (Dekerle et al. 2002), LT (Martin et al. 2000), and the velocity at [La] of 4 mmol.L-1 (V@OBLA; Wakayoshi et al. 1993). It was therefore suggested that CV was a valuable index for evaluating the aerobic capacity of swimmers using a non-invasive method.

On the other hand, the y-intercept of the regression line in the critical power concept (Monod and Scherrer 1965) was called the anaerobic work capacity (AWC) (Vandewalle et al. 1997). In previous studies, AWC has been shown to be related to the highest [La] measured at the end of exhausting running exercise (Vandewalle et al. 1997), the total amount of work during the WAnT (Vandewalle et al. 1989) and the maximal oxygen deficit (Miura et al. 2002). Therefore, it was suggested that the y-intercept of the regression line in the critical power concept would represent an index of anaerobic capacity.

In the critical swimming velocity concept, Oshita et al. (2009) found a highly positive correlation between the y-intercept and the residual error obtained from the relationship between 1500-m performance and CV in Fin-swimming. Besides, when modeling the energetic contribution in swimming, di Prampero et al. (2008) assumed that the y-
intercept would correspond to the distance covered at the expense of the anaerobic energy stores. However, no study has yet directly evaluated the relationship between the y-intercept of the D-T relationship and indices of anaerobic capacity in swimming. In this study it was hypothesized that the y-intercept of the regression line in the critical swimming velocity concept might represent an index of anaerobic capacity. The purpose of the present study was to investigate whether this parameter could be utilized as an index for evaluating anaerobic capacity in competitive swimming.

**METHODS**

**Subjects:** Twenty one well-trained college swimmers (11 males and 10 females) participated in this study. They were varsity swim team members who trained for an average of 2–3 h per session, eight times per week. They took part in national level competitions. Their respective mean height, body mass, and body fat percentage were 1.70 ± 0.07 m, 64.2 ± 5.6 kg, and 17.8 ± 6.6 %. They were informed of the risks of the study and signed an informed consent form.

**Experimental design:** All tests were performed in front crawl in a 25-m swimming pool. A standardized warm-up, which consisted of approximately 2000m for 30min, was performed prior to each test. Within one week, each subject performed a) a maximum swimming effort (50m, 100m, 200m and 400m), b) a 300-m intermittent progressive swimming test, and c) a 30-s all-out Wingate Anaerobic Test (WAnT) performed with arms and legs.

**Determination of CV and the y-intercept:** Fig.1 gives an example of the relationship between D and T for a given swimmer. The linear relationship was drawn, the slope (CV) and the y-intercept were determined from the regression line between D and T.

**Determination of V@OBLA:** Each subject performed a 300-m intermittent progressive swimming test, which consisted of five repetitions of 300m with a 25-minute rest period. Swimming velocities were 60, 70, 80, 90 and 100 % of their maximum effort. [La] was taken from a fingertip immediately after completion of each trial. Blood was analyzed using a blood lactate analyzer (Lactate Pro, ARKRAY). V@OBLA for each subject was determined from the velocity-[La] curve.

**RESULTS**

Mean ± SD for CV and the y-intercept were 1.42 ± 0.09 m·s$^{-1}$ and 15.54 ± 2.92 m, respectively. CV was significantly correlated with the V@OBLA ($r = 0.94, p < 0.05$).

**DISCUSSION**

The present study investigated whether the y-intercept of a regression line between D and T could be utilized as an index for evaluating anaerobic capacity in competitive swimming. The y-intercept was significantly related to highest [La], and the mean and peak power of the WAnT performed with the arms or the legs. This is the first study that evaluates directly the relationship between the y-intercept and indices of anaerobic capacity. This demonstrates the usefulness of determining the y-intercept to evaluate the anaerobic capacity of swimmers in the field.

In the present study, the y-intercept of the D-T relationship was significantly correlated with the highest [La] and the mean and peak power of the WAnT whether the test was performed with the arms or the legs. It has been suggested that the highest [La] and mean and peak power of the WAnT were effective indices of anaerobic capacity, and these indices were significantly related to sprint swimming performance (Lacour et al. 1990, Maglischo 2003, Hawley et al. 1992, Bar-Or 1987). In the critical power concept, the y-intercept called AWC, was found to be related to highest [La] measured at the end of exhausting running exercise (Vandewalle et al. 1997), the total amount of work of the WAnT (Vandewalle et al. 1989), and the maximal oxygen deficit (Miura et al. 2002). Thus, AWC could provide a measurement of the anaerobic capacity, and be related to the ability to perform high-intensity exercise (Dekerle et al. 2002). In the critical swimming velocity concept, di Prampero et al. (2008) assumed that the y-intercept would correspond to the distance covered at the expense of the anaerobic energy stores by applying a model to calculate the energetic contributions of various swimming performances. Further, Oshita et al. (2009) demonstrated a
highly significant correlation between the y-intercept and the residual error obtained from the relationship between 1500-m performance and CV in Fin-swimming. These findings from previous and present studies suggest that the y-intercept of a regression line between D and T in competitive swimming is a valuable index of anaerobic capacity that can be therefore assessed using a non-invasive method.

The findings of this study suggest that applying the CV concept in swimming would enable both aerobic and anaerobic capacities to be evaluated at once without using invasive methods or expensive equipment. Thus, it would provide a simple and effective tool for coaches and swimmers in the field.

CONCLUSION

The y-intercept of the D-T relationship in swimming is significantly correlated with various indices of anaerobic capacity, such as the highest [La], the mean and peak power of the W AnT. From these results, it is suggested that the y-intercept of a regression line in the critical velocity concept could represent a good index of anaerobic capacity, determinable without any invasive measurements.

REFERENCES


Evaluation of Force Production and Fatigue using an Anaerobic Test Performed by Differently Matured Swimmers


University of Porto, Faculty of Sport, Cifi2d, Porto, Portugal

The purpose of this research was to characterize fatigue determining thresholds in force-to-time curves produced during 30 second tethered swimming efforts. Ninety swimmers of three maturational groups took part in the study. Values of maximal, mean, and minimum force were determined, as well as the variation coefficient of the mean force. The anaerobic fatigue thresholds were determined on the individual force-to-time curves, and typical stroke cycles were determined before and after the fatigue occurrence. Typical force cycles were quantitatively analysed. It was possible to conclude that force tends to increase with maturation in males. In females, tethered force seems to stabilize after puberty.

Keywords: anaerobic performance, fatigue, force, tethering swimming

INTRODUCTION

Delaying fatigue is a desire in competitive swimming. In swimming, the use of the anaerobic threshold concept has lead to the growth of scientific knowledge applied to swimming training and seems to keep up with performance evolution. That threshold establishes the border between balanced and unbalanced lactate production and removal (maximal full aerobic and partially anaerobically supported energy production). Fatigue studies of anaerobic function and high power production resisted exercises are not so well developed. It is not clear when fatigue significantly emerges in those efforts and how to get useful information for control and planning of anaerobic swimming training. In a previous study from our group (Soares et al., 2003), we were able to study fatigue and determine fatigue thresholds on velocity-to-time curves obtained in 30 second maximal efforts. Those findings made it possible to improve the control over swimming planning and training in the anaerobic domain. The purpose of the present study was to investigate fatigue and determine fatigue thresholds in force-to-time curves produced during 30 second bouts of tethered swimming.

METHODS

A total of 90 swimmers (Table 1) divided into three maturational groups according to Tanner (Tanner, Whitehouse et al., 1962) performed a 30 second maximal tethered swimming test attached by a non-elastic cord to a strain-gauge system (Globus, Italy). Previously to the starting signal, swimmers adopted a horizontal position with the cable fully extended starting the data collection only after the first stroke cycle was completed. This procedure was used to avoid the inertial effect of the cable extension usually produced immediately before or during the first arm action. The end of the test was indicated by an acoustic signal. Video images were captured during all the tests using a JVC camera (JVC GR-SX25E SFHSC), and individual force-to-time curves [F(t)] were produced for each session.

Table 1. Anthropometric characteristics (mean±SD) and maturational status.

<table>
<thead>
<tr>
<th>Swim level</th>
<th>Pre-pub. - Pre-competition</th>
<th>Pub. - National</th>
<th>Post-pub. - International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>9.4±0.82 b</td>
<td>13.3±0.65 b</td>
<td>18.1±2.35 b</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>34.2±7.21 b</td>
<td>55.3±7.04 b</td>
<td>89.8±7.03 b</td>
</tr>
<tr>
<td>Height, cm</td>
<td>136.47±6.73 b</td>
<td>165.53±8.06 b</td>
<td>176.27±7.49 b</td>
</tr>
<tr>
<td>Tp, s 1-b</td>
<td>1.00±0.00 a</td>
<td>2.00±0.00 b</td>
<td>4.3±0.66 b</td>
</tr>
<tr>
<td>Tc, s</td>
<td>1.00±0.00 a</td>
<td>4.00±1.00 a</td>
<td>4.27±0.70 a</td>
</tr>
</tbody>
</table>

The maximal (Fmax), mean (Fmean) and minimum (Fmin) force values were obtained directly from the F(t) curve and normalized to body weight. The variation coefficient (VC) of Fmean was calculated for each maturational group. Data treatment for fatigue was performed using a routine based on a wavelet analysis, written by our research group, in the MatLab software. The complete routine has already been described by Soares et al. (2006). Before running the routine, the first 2 seconds of the test were removed in order to eliminate the initial peak force. The routine allowed the determination of fatigue thresholds in each individual F(t) curve and the time of occurrence. The intracyclica variation of the force expressed through typical force cycles was established.

Typical force cycles were quantitatively analysed through: (i) total cycle duration time (tcycle); (ii) stroke frequency (SF); (iii) mean cycle force (FmeanC), and (iv) FmeanC VC. Due to technical problems, data of intracyclic force variations are presented for pre-pubertal and pubertal groups only.

Comparison of means between maturational groups was performed through an ANOVA test for independent groups. Gender comparisons were performed using a t-test for independent groups. Normal distribution of data was verified. Significance level was 5%.

RESULTS

The Fmax, Fmean and Fmin values obtained for the male and female swimmers of the three maturational groups studied can be observed in Table 2. The forces produced during anaerobic tethered efforts seemed to increase with maturation, in contrast to VC which tends to decrease.

Table 2. Mean±standard deviation of maximal, mean and minimum force values obtained during the 30 second tethered swimming test.

<table>
<thead>
<tr>
<th></th>
<th>Fmax (%)</th>
<th>Fmean (%)</th>
<th>Fmin (%)</th>
<th>VC of Fmean (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-pub.</td>
<td>14.41±2.79</td>
<td>10.08±2.31</td>
<td>9.25±0.50</td>
<td>1.34±0.19</td>
</tr>
<tr>
<td>Pub.</td>
<td>13.60±3.87</td>
<td>9.44±1.51</td>
<td>8.05±0.55</td>
<td>1.43±0.19</td>
</tr>
<tr>
<td>Post-pub.</td>
<td>14.54±2.60</td>
<td>9.25±0.50</td>
<td>8.05±0.55</td>
<td>1.43±0.19</td>
</tr>
</tbody>
</table>

The number of thresholds obtained in the individual F(t) curves are presented in Fig. 1 (A and B panels). One and two fatigue thresholds were identified in individual F(t) curves, and it was found that increasing level of maturity was associated with only one fatigue threshold.

The time of effort corresponding to the fatigue thresholds is presented in Table 3. In the two threshold participants, the first threshold occurred earlier than in the one-threshold participants.

Table 3. Mean±standard deviation of the fatigue threshold (time, seconds) of the curves with one and two thresholds.

<table>
<thead>
<tr>
<th></th>
<th>One threshold</th>
<th>Two thresholds</th>
<th>First threshold</th>
<th>Second threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-pub.</td>
<td>14.41±2.79</td>
<td>14.54±2.60</td>
<td>10.08±2.31</td>
<td>9.25±0.50</td>
</tr>
<tr>
<td>Pub.</td>
<td>13.60±3.87</td>
<td>13.60±3.87</td>
<td>9.44±1.51</td>
<td>8.05±0.55</td>
</tr>
<tr>
<td>Post-pub.</td>
<td>14.54±2.60</td>
<td>14.54±2.60</td>
<td>9.25±0.50</td>
<td>8.05±0.55</td>
</tr>
</tbody>
</table>

X±SD |

*Significantly different from thresholds of the curves with one threshold at p<0.05.
**Significantly different from both thresholds of the curves with two thresholds at p<0.05.

'n=17; n=20; n=26; n=12; n=9; n=4
Table 4. Mean±standard deviation values (X±SD) of the total swimming time (t), mean duration of each cycle (tcycle), stroke frequency (SF), cycle mean force (FmeanC) and variation coefficient of FmeanC (VC). Values for time intervals defined by the fatigue thresholds of pre-pubertal swimmers.

<table>
<thead>
<tr>
<th></th>
<th>First time interval</th>
<th>Second time interval</th>
<th>Third time interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>t total (s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold</td>
<td>11.96±2.99</td>
<td>13.70±3.36</td>
<td>8.40±2.62</td>
</tr>
<tr>
<td>Two thresholds</td>
<td>7.01±2.05</td>
<td>9.52±2.72</td>
<td></td>
</tr>
<tr>
<td>t cycle (s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold</td>
<td>1.23±0.22</td>
<td>1.35±0.24</td>
<td>1.25±0.13</td>
</tr>
<tr>
<td>Two thresholds</td>
<td>1.14±0.13</td>
<td>1.25±0.13</td>
<td>1.42±0.12</td>
</tr>
<tr>
<td>SF (cycles·s⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold</td>
<td>0.84±0.15</td>
<td>0.76±0.15</td>
<td>0.81±0.09</td>
</tr>
<tr>
<td>Two thresholds</td>
<td>0.88±0.10</td>
<td>0.81±0.09</td>
<td>0.71±0.06</td>
</tr>
<tr>
<td>FmeanC (N·m⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold</td>
<td>24.49±9.78</td>
<td>17.80±7.94</td>
<td></td>
</tr>
<tr>
<td>Two thresholds</td>
<td>16.70±4.13</td>
<td>10.91±6.23</td>
<td>12.77±3.22</td>
</tr>
<tr>
<td>VC (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold</td>
<td>58.25±18.39</td>
<td>61.89±24.95</td>
<td></td>
</tr>
<tr>
<td>Two thresholds</td>
<td>62.89±9.33</td>
<td>62.29±27.75</td>
<td>71.89±18.40</td>
</tr>
</tbody>
</table>

* Significantly different from second time interval at p<0.05.
** Significantly different from third time interval at p<0.05.

From the F(t) it was possible to define the typical force cycle produced during the 30 second effort (Figure 2). In both pre- and post-pubertal swimmers the typical force cycle changed after significant fatigue had occurred.

![Figure 1. Number of swimmers who achieved one or two thresholds in percentage. Results are presented for swimmers of different gender and maturational status.](image1.png)

![Figure 2. Mean cycles of intracyclic variation of the force applied by the right (D) and the left (E) arms. Mean cycles are of the first and second and third time intervals defined by the thresholds. I and II show the typical cycles for pre-pubertal swimmers. Panels III and IV show the correspondent cycles for post-pubertal swimmers.](image2.png)
Table 5. Mean±standard deviation values (X±SD) of the total swimming time (s), mean duration of each cycle (tcycle), stroke frequency (SF), cycle mean force (FmeanC) and variation coefficient of FmeanC (VC). Values for time intervals defined by the fatigue thresholds of post-pubertal swimmers.

<table>
<thead>
<tr>
<th></th>
<th>First time interval</th>
<th>Second time interval</th>
<th>Third time interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>t total (s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold*</td>
<td>11.89±2.79</td>
<td>13.90±2.85</td>
<td></td>
</tr>
<tr>
<td>Two thresholds**</td>
<td>6.90±0.76</td>
<td>8.86±2.24</td>
<td>9.36±1.79</td>
</tr>
<tr>
<td>tcycle (s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold*</td>
<td>1.19±0.11</td>
<td>1.28±0.11</td>
<td></td>
</tr>
<tr>
<td>Two thresholds**</td>
<td>1.07±0.08</td>
<td>1.13±0.08</td>
<td>1.19±0.09</td>
</tr>
<tr>
<td>SF (cycles.s⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold*</td>
<td>0.84±0.08</td>
<td>0.79±0.07</td>
<td></td>
</tr>
<tr>
<td>Two thresholds**</td>
<td>0.94±0.07</td>
<td>0.89±0.07</td>
<td>0.85±0.07</td>
</tr>
<tr>
<td>FmeanC(m·s⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold*</td>
<td>105.29±32.81</td>
<td>86.21±26.66</td>
<td></td>
</tr>
<tr>
<td>Two thresholds**</td>
<td>86.60±34.73</td>
<td>76.66±27.64</td>
<td>67.11±24.05</td>
</tr>
<tr>
<td>VC (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One threshold*</td>
<td>43.58±7.52</td>
<td>47.08±8.81</td>
<td></td>
</tr>
<tr>
<td>Two thresholds**</td>
<td>38.75±14.24</td>
<td>37.00±8.98</td>
<td>41.50±8.10</td>
</tr>
</tbody>
</table>

*Significantly different from second time interval at p<0.05.
**Significantly different from third time interval at p<0.05.
\n\nDiscussion

It has also been found before, that tethered swimming force rises with maturational status in males and in females and stabilizes after puberty (Blimkie & Sale, 1998; Zauner, Maksud et al., 1989). Thus, it was no surprise that force produced during anaerobic tethered efforts in our study also tended to increase with maturation. In contrast, the VC tended to decrease, which possibly reflects a maturity-paralleled combined effect of improved force and technique.

It has also been previously observed that in swimmers (Soares et al., 2006) it was possible to identify one to two fatigue thresholds on individual velocity-to-time curves. Young and less mature swimmers seemed to fatigue more during the 30 seconds than the older and more mature swimmers. Post-pubertal swimmers tend to significantly reduce tethered force only once during the 30 s effort, which seems to traduce a capacity to maintain higher levels of force production. Young swimmers, possibly due to lower force capacity levels and/or technical ability, tend to fatigue twice. The first point occurred sooner than in the older swimmers, and they were unable to sustain the "second stage of force" until the end of the effort, as constituted by a second drop .

The typical force pattern changes after the occurrence of the fatigue thresholds evidences the fatigue effect in the swimmers technical ability, which seems to be independent of gender and maturation. This negative effect could be observed either by visual inspection of the typical cycle profile or by the changes in quantitative parameters. After fatigue occurs, the VC of Fmean, and the cycle duration time tends to increase, and the SF and the Fmean tend to decrease.

In general, it was observed that the first threshold occurred after approximately 14 seconds (one fatigue threshold) and 10 s (two fatigue thresholds). These findings are in accordance with the theoretical values already suggested in the literature as the possible limit of the alactic energy system (Brooks, Fahey et al., 2000; Gastin, 2001). The definition of a threshold like this one could be of great importance for training planning and control, the purpose of coaches being to move the threshold to the right along the time line. The second threshold happened at around 19 seconds, and is possibly a consequence of the altered recruitment pattern of the muscular fibres.

Conclusions

Swimmers of both genders have similar levels of maximum, mean and minimum force obtained in tethered swimming. These forces tend to increase in males with maturation. In females, tethered force tends to stabilize after puberty. The variation of the mean force tends to decrease with maturation, possibly due to improved swimming technique. It is possible to determine changes in F(t) curves that may be associated with the idea of "fatigue thresholds". There are a greater number of curves with two fatigue thresholds (except for the post-pubertal swimmers). It is possible to define typical stroke cycles before and after the fatigue threshold occurrence both graphically and quantitatively.

References


Identification of a Bias in the Natural Progression of Swim Performance

Stager, J.M. 1, Brammer, C.L. 1, Tanner, D.A. 1

1Indiana University, Bloomington, USA

The longitudinal progression of athletic records has been described by best fit curves which can be used to extrapolate future athletic performances. Any subsequent significant deviations from these curves would suggest compelling evidence of cataclysmic changes introduced into the sport. We evaluated recent elite swim performances to determine if bias can be identified within competitive swimming. Predictions of the 2008 Olympic swimming competition were calculated for each event and compared to actual performances. 17/26 events in 2008 were significantly faster than predicted (p<0.05). A bias existed during the 2008 Olympic Games such that performances were faster than predicted. Speculation of the causes of this observation include but are not limited to new swim suits, ergogenic aids, better training, and improved technique.

Key words: 2008, freestyle, Olympic, prediction, suits, swimming, technology, trend

INTRODUCTION

In the past, scholarly interest in the prediction of the boundaries of human performance has largely focused upon performance in running events. Similar to swimming, in running there is very little technology involved in competition and little required by the track athlete beyond a pair of shoes. Initial analyses in track, as a means to predict future performances, relied primarily upon linear regression models to predict future athletic records. Criticism of this approach includes the observation that linear models do not allow for an ‘ultimate limit’ to human performance. For example, given enough time, the linear models predict “humans will run negative world record times” (Nevill, 2005). While this is clearly absurd, linear models of performance do not allow or accept that there may be physiological, anatomical and biomechanical limitations that simply cannot be overcome by better training, more practice or better protoplasm.

Neither do these early linear models take into account improvements in such factors as nutrition, coaching knowledge, sociological and or economic factors that might influence performance (in either direction). Finally, linear models do not account for the fact that the characteristics of the competitors and competition used to generate the model may influence the slope of the generated progression line. If the sport has only recently been introduced, then it stands to reason that the rate of improvement will be greater early on as compared with that observed twenty or thirty years later simply as a matter of the sport itself approaching competitive maturity. For example, one analysis of women’s events suggests that their performances are improving at a greater rate than are the men’s (Whipp, 1992). As a result, linear analysis suggests that eventually, in some events, the women’s records will eclipse those of the men. While not impossible, it is more likely that the relationship is not linear and that with time the rate of improvement in women’s records will slow and become similar to that seen in the progression of the men’s records.

Studies subjecting swimming performance to mathematical analysis to describe, compare, and predict the change in records over time have been conducted since the beginning of the 20th century. The variable rate of record progression has led authors to use S-shaped logistic (Nevill, 2005), second order polynomial (Seiler et al., 2007), and multiple exponential decay (Berthelot et al., 2008) models to illustrate swim performance progression. Although these types of curves may better fit historical data, they necessarily include variation due to chance modification of performance. If these models are to be used to predict future performance, then they must minimize historical and undefined chance influences since these factors are inherently unreliable (Frick, 1964). Rather, it is likely that a single parabolic curve, one that carries a certain range of error and asymptotically approaches a describable limit, better describes the systematic progression of swim performance (Figure 1).

One caveat to any mathematical analysis of swim performance (and subsequent prediction of swim performance) based upon prior performances, is to accept that undefined and confounding variables may introduce biases into the analysis and potentially perturb the ability of any subsequent model to be accurate. For example, documented use of performance enhancing pharmacological compounds during the early to mid 1970’s may have caused an overestimation of the rate of potential improvements in subsequent years. In other words, performances subsequent to this era will appear as if something has caused a slowing of the progression rather than the “return to a normal ‘unbiased’ progression”. As time goes by, however, additional performances will correct the model allowing for earlier unconfirmed biased performances to be obvious (assuming that which caused the bias is no longer present). However, the causes of the temporary perturbations will be speculative, at best, until reinforced by historical confirmation.

Using the top eight performances in each event at recent Olympic Games from 1972 through 2004, an “expected” or “forecasted time” can be calculated for the 2008 Games. The objective of this study was to test the accuracy of these predictions by comparing them to actual performances. Further, to assess the validity of the model, these procedures were repeated for the 1988, 1992, 1996, 2000 and 2004 Olympics. Finally, if it appears reasonable that this prediction curve is valid, then any significant deviations from it would suggest compelling events, biases or cataclysmic changes have occurred within the sport. It is hypothesized that the accuracy of the predictions may fail as a function of unusual events in the world of swimming such as boycotts, drug use, or perhaps newly introduced swimsuit technology.

METHODS

The top eight times from the finals of Olympic swimming events from 1972 through 2004 were analyzed for mean and standard deviation. A best-fit power curve of the form $y = ax^b$ was calculated across all years for each event, where a and b were coefficients and year was the code for the year of the Olympics (1 = 1972, 2 = 1976, ..., 9 = 2004). Using year = 10 to indicate 2008, the power equations were used to predict the mean of the finalists for each event of the 2008 Olympics. The percent difference between the predicted time and the actual time (absolute value)
was calculated for each year and averaged within each event. This number was used to estimate the standard deviation of the predicted time for each event using the formula 1.25*(mean percent difference)/(predicted value)/100. This standard deviation was used to establish the 95% confidence interval for each event (predicted time ± 2 standard deviations).

The mean time of the finalists of the 2008 Olympics were compared to this 95% confidence interval and actual times that fall outside the interval were concluded to be significantly faster or slower than predicted.

To examine each Olympic year as a whole, a count was made of the number of events for which the actual time was above or below the corresponding prediction curve. A binomial test of statistical significance was used to test whether or not the likelihood of the number of events being either faster or slower than our predictions was different than 50%. This table of event counts was tested to determine whether or not a particular year was faster or slower, in general, than predicted.

To test the repeatability of this prediction method, the same calculations were performed to compare actual versus predicted performances of the 2004 Games using data from 1972 through 2000 only. These procedures were repeated for all Olympic Games 1988-2000 (using data since 1972).

RESULTS

**Prediction Analysis:** For the 2008 Olympic Games, 10/13 (77%) men and 7/13 (54%) women’s events recorded mean times for the eight finalists that were significantly faster than the predicted outcome values. Only 34% of the events in the 2008 Games were successfully predicted. Between 1988 and 2004, 10/61 (16%) men’s events were significantly faster and 1 (2%) event was significantly slower than predicted. For the women, 1/61 (2%) events was significantly faster and 9 (15%) events were significantly slower than predicted. That is, 87% of all events were successfully predicted. These results are presented in Table 1 and Figure 2.

Table 1. Comparisons between predicted and actual Olympic final performances for men, women, and combined (1988-2008). The performances of the women were significantly slower than expected (p < 0.05) in 1992 and 1996. During the Olympic Games (1988-2004), the performances of the women were significantly slower than expected (p < 0.05) in 1992 and 1996. However, the Games in 1988, 1992, 1996 and 2004 were as expected. The men and women combined swam significantly slower than expected (p < 0.05) in 1996, significantly faster than expected in 2000 (p < 0.05). However, the Games in 1988, 1992, 1996 and 2004 were as expected. The men and women combined swam significantly slower than expected (p < 0.05) in 1996, significantly faster than expected in 2000 (p < 0.05), and as expected in 1988, 1992 and 2004.

**Binomial Analysis:** Finally, the results of binomial tests of statistical significance are presented in Table 2. At the 2008 Games, all 26 events (13 men and 13 women) were faster than our predictions. That is, all events lay below the prediction curve, but were not necessarily significantly faster than predicted. As a result, the binomial test of statistical significance revealed that the 2008 Olympic swimming event was, as a whole, significantly faster than expected (p > 0.05). For prior Olympics (1988-2004), the performances of the women were significantly slower than expected (p < 0.05) in 1992 and 1996. During the Olympic Games in 1988, 2000 and 2004, however, women swimmers performed as expected. Meanwhile, performances of the men were significantly faster than expected in 2000 (p < 0.05). However, the Games in 1988, 1992, 1996 and 2004 were as expected. The men and women combined swam significantly slower than expected (p < 0.05) in 1996, significantly faster than expected in 2000 (p < 0.05), and as expected in 1988, 1992 and 2004.

Table 2. Count of events that were faster or slower than our predictions (above or below the regression line) for men, women, and combined men and women categories for each Olympic Games (1988-2008). The results of the binomial test of statistical significance shows the probability that this many events will be slower (†) or faster (*) than predicted is less than 5% (p < 0.05).

![Figure 2. Percent of total events successfully predicted (within 95% C.I.) for each Olympic Games (1988-2008) for men, women, and combined men and women categories.](image-url)

![Figure 3. Average difference, in standard deviations, between actual and predicted performances of Olympic swimming events (1988-2008). A positive value denotes the average of actual event means were faster than the predicted event means. * denotes significant difference compared to all other groups.](image-url)
DISCUSSION
The results of the 2008 swimming competition were, in general, exceptionally fast and do not fit the expectations of our mathematical modelling and based upon prior performances. With the exception of the 1996 Games (which resulted in performances that were significantly slower than expected), there is little to no evidence to suggest any pervasive performance enhancing bias existed before 2008 for men or women. The exception (using binomial analysis) might be 2000 when the full body suits were first introduced. Until now, our predictive modelling was largely successful in describing swim performance at the elite level. We would conclude that this bias had a dominant role in enhancing performance in a manner inconsistent with the natural progression of swim performance observed over the last half century.

Personal communication with coaches and athletes at this level has not provided any evidence of innovation other than perhaps the introduction of new technology suits into the sport. Due to the nature of commerce and claims of “proprietary” knowledge, very little specific data exist identifying the magnitude (if any) of the effect of the newest generation suits on swim performance. While the current study does not directly measure the effect of the new technology swim suits, the athletes and their performances suggest that these suits (which did not exist prior to 2008) have introduced unnatural rates of improvement into the sport.

Finally, if the great leap in performance is not due to the introduction of the suits and due to better coaching or enhanced coaching techniques, then the “bias” should persist in future performances. If not, this leads to the hypothesis that future analyses of swim performance will show a correction such that 2012 will be slower than predictions suggest. The slope in the progression of performance will be similar to what existed prior to 2008 and 2008 will be judged as anomalous. Ultimately, the progression in times will slow as swimmers approach the inescapable limits of human performance.

REFERENCES

ACKNOWLEDGEMENTS
The authors are indebted to the graduate students of the Counsilman Center for the Science of Swimming at Indiana University.

Tethered Swimming as an Evaluation Tool of Single Arm-Stroke Force

Toumbekis, A.G., Gourgoulis, V., Tokmakidis, S.P.

1Kapodistrian University of Athens, Athens, Greece,
2Democritus University of Thrace, Komotini, Greece

Eight competitive swimmers performed a series of maximum intensity tethered swimming tests using full-stroke, arms only, right and left arm only. In all tests, the force of each arm-stroke was determined. The validity of each arm-stroke separation was tested in advance using over-water and underwater video recordings (ICC=0.939, and 0.974, p<0.05). The reliability of force measurement for each arm-stroke was tested in a separate group of swimmers (ICC=0.985, and 0.975, p<0.05). Swimming force was not different between right and left arm-stroke in all tests (p<0.05). Right and left, single arm-stroke forces were correlated between tests (r=0.79 to r=0.92, p<0.05). Specific force of each arm-stroke can be reliably measured during tethered swimming using a valid separation of each arm-stroke.

Key words: propulsive force, arm-stroke separation, specific swimming strength

INTRODUCTION
Swimming forces can be evaluated by using three-dimensional underwater video analysis (Gourgoulis et al., 2008), pressure differences on the hand (Takagi & Wilson 1999), tethered (Kjendlie & Thorvald 2006) or semi-tethered swimming (Keskinen 1994). Tethered swimming seems to be the most convenient, easy and time-saving procedure compared to other methods. This method has been used as an evaluation tool of the specific swimming force (Kjendlie & Thorvald 2006; Keskinen, 1994), the ability level of young elite swimmers (Vorontsov et al., 2006) and has been tested for reliability during swims of maximum effort (Kjendlie & Thorvald 2006). Keskinen (1994) extended the application of semi-tethered swimming in combining force and velocity data using video-recording to separate arm-stroke phases. Since the study of Keskinen (1994) there are no reports of force variations during separate arm-strokes using tethered swimming. Additionally, the procedure applied by Keskinen (1994) requires the simultaneous use of a video-recorder and a force transducer and is not easily applicable during field testing.

It is interesting to examine the feasibility of measuring the tethered swimming force of each arm separately without the help of video-recording. This could provide an easy means of specific single arm force evaluation. However, there are no reports for the reliability of testing the tethered swimming force of each arm separately. An accurate separation of each arm-stroke during a tethered swimming test requires the input of a signal into the system that should be synchronized with the force recording. The validity of the signal input procedure, for arm-stroke separation, should be tested by using video-recording simultaneously. Thus, the purpose of the study was to examine the validity of the arm-stroke separation and the reliability of a single arm-stroke force evaluation during a tethered swimming test.

METHODS
Six female and two male of similar performance level (National level), well-trained swimmers participated in the study (n=8, age: 14.7±1.4 yars, body mass: 64.8±10.8 kg, height: 1.66±0.08 m). The participants and their parents were informed in detail on the experimental risks and signed an informed consent document prior to the investigation. All swimmers performed four tethered swimming tests: 15 s using full-stroke (SW), 15 s using arms only (ARM), five strokes using the right arm only (1ARM-R) and five using the left arm only (1ARM-L). During the 1ARM-R and 1ARM-L tests, leg-kick at maximum intensity...
was used in addition to arm-strokes. During the ARM test a floating device was used to keep legs together in a horizontal position. A zero velocity was maintained in all tests.

The force for SW and ARM tests was averaged for 15 s. In addition, the force for each right and each left arm-stroke was measured for the first five stroke cycles during the SW and ARM tests and during five strokes of the 1ARM-R and 1ARM-L tests. Additionally, a qualitative representation of force variation during the fourth stroke cycle of the SW and ARM test was applied. All tests were applied at maximum intensity and completed within two consecutive days. Each test started with slow swimming and with countdown from three. The swimmers applied maximum intensity after the examiner’s commands and the start always coincided with the entry of the right hand in the water, while using the front crawl style in all tests. A standard warm-up was applied before each test (400-m swim, 4×50-m progressively increasing intensity, 2x6s tethered swimming sprints). All swimmers had been familiarized with the procedures on a previous day.

During tethered swimming tests a piezoelectric force transducer connected to an analog to digital (A/D) converter system (MuscleLab, Ergotest) with a sampling frequency 100Hz was used for force measurement. A trigger was used to insert a signal synchronized with force recordings into the system, and separated the arm-strokes. The button of the hand-held trigger was pressed by the experimenter at the moment of each arm-stroke entry in the water. In a separate experiment a female swimmer performed 10×20-arm-stroke trials videotaped above water and 6×20-arm-stroke trials videotaped underwater in order to validate the accuracy of stroke separation using the hand-held trigger. Using a small LED emitting light, the signal of the hand-held trigger was synchronized with a camera (Sony DCR-HC14 E, Sony Corporation, Japan) operating in interlaced scan mode (50Hz), which was located perpendicular to the swimmer. A different group of swimmers (n=7, age: 13.8±1.5 years, body mass: 58.5±7.6 kg, height: 1.67±0.08 m) was used to test the reliability of force output for each arm-stroke. The swimmers performed a 15 s sprint with the same procedure as described above (test 1) and repeated the test within seven days (test 2). The force of the first ten arm-strokes of the two tests was compared.

Analysis of variance for repeated measures on two factors (tests x arms) was used to examine force differences between tests and between arms. Differences between means were located using a Tukey post-hoc test. The Pearson correlation coefficient was used to test the relationship between variables and the intraclass correlation coefficient (ICC) was used to examine the reliability of the procedures. The results are presented as means±SD and the accepted level of significance was set at p<0.05.

RESULTS

The mean force of the right (R) and left (L) arm-strokes was not different between test 1 and test 2 in the group testing the reliability (mean force; Test 1, R arm-stroke: 122.5±23.1 N, L arm-stroke: 128.4±21.2 N; Test 2, R arm-stroke: 119.9±24.0 N, L arm-stroke: 127.9±28.5 N, p>0.05). The R and L arm-stroke ICC confirmed the reliable force reproduction in each arm-stroke (R arm-stroke, ICC=0.985; L arm-stroke, ICC=0.975 p<0.05). Furthermore, no difference was observed between test 1 and test 2 in any of the ten strokes (p>0.05, Figure 1). The average time to complete each arm-stroke calculated by video recording, by the LED emitting time and by the hand-held trigger was no different (video time over-water: 0.732±0.065 s, LED time: 0.748±0.070 s, hand-held trigger time: 0.747±0.069 s, p>0.05). In addition, the reliability of the hand-held trigger use was confirmed with the over-water and underwater video recordings (ICC=0.939 and 0.974, p<0.05). The time error of the arm-stroke separation with the hand-held trigger was no more than a video frame (i.e. 0.020 s, p>0.05). The absolute difference between video-recorded stroke time (under-water and over-water) versus the trigger hand-held time measure was not significant (under-water video recorded stroke time vs. hand-held trigger time: 0.024±0.026 s and over-water video recorded stroke time vs. hand-held trigger time: 0.018±0.022 s, p>0.05).
DISCUSSION

The findings of the present study indicate that a reliable measurement of swimming force for each arm can be achieved using tethered swimming. The procedure used for the separation of arm–strokes during front crawl was proved to be valid when it was compared with over-water and under-water video recordings. Using three different tethered swimming tests (full-stroke, arms only, single arm) no differences were observed between right and left arm–stroke force.

Previous studies have shown a high reliability for the measurement of the maximum swimming force in a 10 s tethered swimming test (Kjendal & Thorsvald 2006). However, there are no data concerning the reliability of measuring the force output during a single arm–stroke during tethered swimming. In order to measure the force of each arm–stroke independently during a test, a valid separation of the strokes is required. In the present study the time calculated to complete each arm–stroke from a video and from a hand-held trigger was similar (p>0.05). This means that the input of the electrical signal using a hand-held trigger can separate arm–strokes with validity (ICC=0.974 and 0.939). In practice, the force variation within this time frame can be measured. Applying these procedures with a group of young swimmers, the force was measured with reliability (ICC=0.985 and 0.975, p<0.05). Additionally, the three different tests used for single arm force measurement showed a similar pattern of force changes in the R or L arm–strokes (Figure 3). The present study simplifies the evaluation of force within a single arm–stroke without the use of sophisticated analyses, such as those used by Keskinen (1994). However, it is not possible to observe the force variation of an underwater movement (pull or push phases) as it was applied by Keskinen (1994).

It has been observed that tethered swimming may alter the depth of arm movements compared to free swimming (Maglischo et al., 1984), but it is not known if tethered swimming alters the force output. Whatever the case, the ease of a tethered swimming test gives the opportunity for repeated testing and fast access to force information. Furthermore, the valid separation of arm–strokes during full-stroke or single-arm swimming tested in the present study, gives the opportunity to examine the specific strength differences between the arms. Furthermore, combining this easily applicable in-water test with an out of the water strength test, coaches and scientists may locate the arm–stroke with the less efficient application of force in the water and may reveal between-arm weaknesses. This does not imply that single arm–stroke force measured with tethered swimming should replace valid techniques used for swimming force evaluation (Gourgouli, 2008). Tethered swimming tests such as those described in the present study may be used for an easy and time-saving testing of a large number of swimmers, while providing reliable information to coaches.

It is also interesting to note that when the force variation of arms only and full-stroke was presented relatively to the percentage of the stroke cycle times, the force variations within a stroke cycle were similar (Figure 4). However, it should be noted that when measuring the force of one arm, that some force has also been applied by the opposite arm, cannot be overlooked since an overlap between arms is probably occurring, especially during sprinting. In addition, during the one arm tests (1ARM) the force produced by the legs cannot be ignored. Whatever the case, using a single-arm tethered swimming test the force of each arm separately can be estimated.

CONCLUSION

The measurement of in-water specific force applied by each arm may be an easy and time saving manner to help coaches to locate force differences between right and left arm–strokes during swimming. However, in this case, whether any difference is attributed to technical or physical factors cannot be discriminated. Future studies combining in-water with out of the water single–arm strength measurements may help coaches to gain information concerning the efficiency of force application of each swimmer. Measuring the specific force of each arm–stroke with a valid separation of arm–strokes is a reliable procedure.

REFERENCES:


Blood Lactate Responses During Interval Training Corresponding to Critical Velocity in Age-Group Female Swimmers

Tsalis, G.1, Toubekis, A.G.2, Michailidou, D.1,ourgoulis, V.3, Douda, H.1, Tokmakidis, S.P.1

1Aristotle University, Thessaloniki, Greece,
2Kapodistrian University of Athens, Athens, Greece
3Democritus University of Thrace, Komotini, Greece

The present study examined the blood lactate responses of female swimmers at intensity corresponding to critical velocity (CV). Eight children (C), eleven youth (Y) and seven adults (A) were timed in distances of 50, 100, 200, 400 m for the CV calculation. On a following day the C performed 5x300 m and the Y and A 5x400 m repetitions with 30-40 s interval, at CV. Blood lactate concentration ([La]) was similar between groups and maintained steady within a range of 3.5±1.2 to 5.1±1.6 mmol·L−1 (p>0.05). RPE and RPE/[La] ratio were no different between groups (p>0.05) and increased after the second and third repetition respectively in all groups (p<0.05). During 28-31 min intermittent swimming, children, youth and adult female swimmers are able to sustain CV with a steady [La] despite an increased subjective perception of fatigue.

Key words: aerobic training, lactate threshold, lactate steady-state

INTRODUCTION

It has been suggested that critical swimming velocity (CV) can be maintained for a long time without fatigue (Wakayoshi et al., 1993). However, in practice it is recognized that interval swimming at a velocity corresponding to CV will progressively increase blood lactate concentration and may lead to fatigue in less than 30 minutes during continuous (Dekerle et al., 2009) or intermittent swimming (Ribeiro et al., 2008). Although, this is evident in adult swimmers, the child swimmers showed different metabolic responses and maintained steady-state lactate concentration over the same period (i.e. 20-30 min; Filipatou et al., 2006). Furthermore, the CV of youth and child swimmers of 10 to 15 years old has been shown to be similar to the velocity of a 30 minute continuous swim (Greco and Denadai 2005; Fernandes and Vilas-Boas 1999) or similar to lactate threshold (Toubekis et al., 2006). Several reasons may have caused these differences. It is possible that the different distances selected for the CV calculation and the different times required to cover a given distance between age-groups could explain these observations. Furthermore, differences in swimming economy may contribute to the different metabolic responses observed in children compared with youth or adults when swimming at a velocity corresponding to CV. In most of the studies male swimmers have been used and there is only limited evidence concerning female swimmers (Greco and Denadai 2005; Fernandes and Vilas-Boas 1999). The purpose of this study was to examine the lactate responses of female swimmers of different ages during interval swimming at a velocity corresponding to CV.

METHODS

Three groups of female swimmers; eight children (C), eleven youth (Y) and seven adults (A), participated in the study (C; age: 10.4±0.6 yrs, height: 1.43±0.07 m, body mass: 36±6 kg, Y; age: 13.1±0.4 yrs, height: 1.62±0.06 m, body mass: 51±7 kg, A; age: 19.9±4.4 yrs, height: 1.74±0.04 m, body mass: 62±5 kg). The stage of biological maturation was assessed according to pubic hair and breast development (Tanner and Whitehouse, 1976). All swimmers were timed over the distances of 50, 100, 200, 400 m and the slope of the distance vs. time relationship was calculated and identified as CV (Wakayoshi et al., 1993). The distances of 50 and 400 m were timed on the first day and the distances of 100 and 200 m on the second day after a standard warm-up. Ten minutes of easy swimming and at least 15 minutes of passive rest was
allowed between tests. Swimmers were not tested if they didn't feel completely recovered after the first tested distance.

On a following day swimmers performed five repetitions of 400 m or 300 m with an interval of 30-40 s (5x400 m, Y and A groups; 5x300 m, C group). During the set the swimmers were guided to maintain CV. The 300- m distance was used for children swimmers in order to keep the duration of each repetition similar among groups. A capillary blood sample was taken from a finger-tip after each 400 or 300 m repetition. The short resting interval between repetitions was used for blood sampling (30-40 s). The blood sample was immediately mixed with 10 volumes of 0.3 molL⁻¹ perchloric acid and centrifuged at 1500 x g. The supernatant was stored and later analysed spectrophotometrically at 340 nm wavelength using reagents commercially available (Sigma, St Louis, MO). The RPE was reported after each 300 or 400 m repetition on a 10-point scale.

A two-way analysis of variance for repeated measures (group x repetitions) and the Tukey post-hoc test were used for statistical analysis. The Pearson correlation coefficient was used to examine the relationship between variables. The results are presented as mean±SD and the level of significance was set at p<0.05.

RESULTS

Swimmers of group C, Y and A were at the stages of 1.0±0.0, 3.5±0.8 and 5.0±0.0 according to Tanner's scale. Performance times of each group for the distances of 50, 100, 200 and 400 m were used for the CV calculation are shown in Table 1.

Table 1. Performance time of 50, 100, 200, 400-m distances used for the CV calculation in each group of female swimmers.

<table>
<thead>
<tr>
<th>Group</th>
<th>50 m</th>
<th>100 m</th>
<th>200 m</th>
<th>400 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children</td>
<td>37.7±1.5</td>
<td>85.7±4.8</td>
<td>191.8±10.4</td>
<td>400.4±18.9</td>
</tr>
<tr>
<td>Young</td>
<td>32.4±1.3</td>
<td>71.5±2.9</td>
<td>157.9±9.2</td>
<td>332.3±23.0</td>
</tr>
<tr>
<td>Adult</td>
<td>31.1±2.2</td>
<td>68.2±3.6</td>
<td>151.3±5.6</td>
<td>315.2±14.6</td>
</tr>
</tbody>
</table>

The critical velocity of Y and A was greater than the C group (C: 0.962±0.05, Y: 1.168±0.09, A: 1.217±0.05 m·s⁻¹, p<0.05) but was not different between Y and A groups (p=0.05). The CV corresponded to 96.1±0.6, 96.5±1.1, 96.4±0.7% of the 400 m velocity. During the 5x300 or 5x400 m repetitions the actual velocity was held constant (C: 0.967±0.05, Y: 1.147±0.08, A: 1.189±0.06 m·s⁻¹; Figure 1). The actual velocity corresponded to 100.5±1.7, 98.3±2.8 and 97.8±2.9% of the CV and these percentages were no different between groups (p=0.05). Additionally, the sustained actual velocity during the interval swimming set of repetitions was not different from the CV, for all groups (Figure 1, p=0.05). The average time required to cover the 300 or 400 m distance repetitions (C: 5.2±0.2 vs. Y: 5.8±0.4 and A: 5.6±0.3 min, p=0.05) and the total time needed to complete the five repetitions (27.9±1.2, 31.2±2.0 and 30.1±1.4 min, p=0.05) was shorter for the C group than for the Y and A groups.

Blood lactate concentration during the set was not different between groups and was maintained steady during the repetitions of 300 or 400 m in all groups ([La] range, C: 4.1±1.1 to 4.9±1.2 mmol L⁻¹; Y: 4.4±1.3 to 5.1±1.6 mmol L⁻¹; A: 3.5±1.2 to 4.1±1.6 mmol L⁻¹; Figure 2, p=0.05). RPE was not different between groups and increased after the second, third, fourth and fifth effort compared to the first 300 or 400 m repetition, independently of group (Figure 3, p=0.05). The RPE/[La] ratio was not different between groups and increased after the third compared to the first 300 or 400 m repetition independently of group (Figure 3, p=0.05). The percentage of the average velocity achieved during the repetitions was negatively correlated with CV (r=-0.49, p<0.05).

DISCUSSION

Female swimmers present a steady-state lactate concentration as they maintain a velocity corresponding to CV during interval swimming. It seems that female swimmers within an age range of 11 to 19 years, show similar lactate responses during an aerobic endurance training set with a velocity corresponding to CV.

The [La] measured in the present study is lower compared to that reported for male adult and youth swimmers but similar to that reported for male children (Filipatou et al., 2006; Ribeiro et al., 2008). Male swimmers during a similar protocol showed a lactate concentration progressively increasing (5 to 8 mmol L⁻¹) compared to the steady-state of 3.5 to 5 mmol L⁻¹ in the present study (Filipatou et al., 2006; Ribeiro et al., 2008). However, a steady-state lactate concentration was observed (4.5 to 5.5 mmol L⁻¹) in a series of 10x400-m in a recent study by Dekker et al. (2009), as has been reported in early studies during 4x400-m repetitions (Wakayoshi et al., 1993). The lower blood lactate concentration of youth and adult female swimmers may be attributed to decreased carbohydrate utilisation caused by sex-hormones in females (Braun &
A reduced carbohydrate utilisation may decrease the [La] levels in females compared to males exercising at the same relative intensity (Deschenes et al., 2006). The relative intensity in the present study (96% of 400 m velocity) was similar to previous studies calculating the CV with the same combination of distances in males (Filipatou et al., 2006). It is also important to note that the time to complete each distance is shorter in male swimmers than female swimmers while using the same distances for CV calculation. This may underestimate the slope of the distance vs. time relationship, while the lower [La] may overestimate the boundary between moderate and severe exercise intensity domains for females. Thus, it may be easier for female swimmers to complete a series of repetitions at this velocity since they swim with decreased metabolic stress. As a consequence, a steady [La] during the 5x400 or 5x300 m repetitions was evident.

In the present study, female adults showed similar blood lactate concentrations to children and youth swimmers. During the 5x300 or 5x400 m all swimmers maintained a velocity similar to CV, however, the adult and youth swimmers swam at 98%, while children at 100% of the CV. This percentage of velocity variation was not statistically different between groups nor was the blood [La]. However, a small difference of 2% may be enough to alter the lactate responses as has been seen with male adult swimmers (Takahashi et al., 2009). This was not observed in the present study. Children show faster oxygen and blood lactate kinetics than adults (Fawkner & Armstrong, 2003; Beneke et al., 2005) and may eliminated blood lactate faster than Y and A swimmers despite a 2% higher intensity. Furthermore, a likely better swimming economy for the A and Y groups than for the C group may help to maintain a low [La] (and similar in all groups).

The CV was calculated from the same distances in all groups, however, the C group needed more time to complete each distance (Table 1). This may have underestimated the CV calculation in the C, or overestimated it in the Y and A groups. Thus, it is likely that swimmers in the C group perceived the maintenance of the CV pace to be easier than the Y and A groups. In support of this, the [La] in the C group was slightly lower during the last three repetitions, and RPE was lower at least at the beginning of the set (although both not statistically different). Because of the different duration of the four trials between the three groups, CV calculated and eventually sustained during the interval swimming could have corresponded to different relative exercise intensities. Although, all groups exercised at 96% of the 400 m velocity, this intensit was not similar relative to the lactate threshold or maximum oxygen uptake between groups. Whatever the case, the negative relationship between CV with the percentage of velocity sustained during the training set in the present study indicates that the faster swimmers may have difficulty in maintaining CV. This observation confirms our argument that the longer distance of repetitions used to calculate the slope of distance vs. time (slow swimmers) may lead to an underestimated CV value which in turn is easier to sustain since it is located in a lower exercise intensity domain.

Changes in O$_2$ uptake and heart rate data may help to characterize the exercise intensity domain. The intermittent protocol and the limited data of the present study do not allow characterization of the CV within the exercise intensity domains. Such a characterization possesses inherent difficulties for children (Williams et al., 2008) and additional constraints in swimming. Recent data show that continuous swimming at the CV may be within the severe intensity domain (Dekerle et al., 2009). In contrast, findings from other studies support the opinion that swimming at CV corresponds to the maximum lactate steady state (Takahashi et al., 2009). However, distances of 100, 200, 400 and 800-m (Dekerle et al., 2009) or 50, 300, 2000-m (Takahashi et al., 2009) were used and any comparison with our data is not appropriate.

The duration of 5x300 or 5x400-m repetitions was 28 to 31 minutes and [La] was steady from the first to the last repetition. However, the RPE values increased progressively reaching “very hard” if not “maximal” on the scale (>8 in the 10-point scale). It is interesting to note that eight of the swimmers (four in the C group) reached “maximal” values in the RPE scale. Increased RPE to [La] ratio after the third repetition may be a sign of fatigue caused by the exercise duration when the intensity remains constant.

**CONCLUSION**

Critical velocity calculated by slope of the distance vs. time relationship using distances of 50, 100, 200, 400 m, can be sustained during intermittent swimming for 28 to 31 minutes in female swimmers of eleven to nineteen years of age. Irrespective of the age-group, female swimmers display steady-state and similar blood lactate responses during intermittent swimming at a velocity corresponding to critical velocity, and this is in contrast to previous findings in male swimmers.
REFERENCES


Monitoring Swim Training Based on Mean Intensity Strain and Individual Stress Reaction of an Elite Swimmer

Ungerechts, B.E.¹, Steffen, R.², and Vogel, K.³

¹University of Bielefeld, Germany,
²Coaches Academy Cologne, Germany,
³German Sport University Cologne, Germany

Swim coaches prescribe training to enhance the properties required for a person to swim the same distance in less time. Monitoring training strain may give a clue to the relationship between training and race performance. Mujika (1996) monitored a training season reducing training components to one MITS-value (mean intensity of a training season). Since training strain is modulated by personal traits into an internal fatigueing impulse, cooperation by the athlete is essential to monitor the perceived stress at the end of a day and the next morning, respectively. The difference of both items, called delayed perceived fatigue, and MITS-value of a world level female swimmer was registered for 144 days: MITS = 2.01 ± 0.12 and the delayed perceived fatigue = -1.31 ± 1.81 arbitrary units, respectively. The increase of the race performance was 2.8%.

Key words: training intensity, perceived stress, training monitoring, elite swimmer

INTRODUCTION

Swim coaches prescribe training to enhance the properties required for a person to swim the same distance in less time. Occasionally coaches are interested in different concepts after e.g. realising that training principles do not really tell how training loads are related to reactions of the biological systems or when working with elite swimmers, which was the case here. Coach, swimmer and consultant realized that in the past the daily training routine served to cause adaptations but a causal predication about the impact of training volume and intensity and the race performance or e.g. blood parameters could not be indentified (Nissen et. al., 2007). They started mutual reasoning concerning training contents and efficient monitoring and were interested in what scientists who had long worked in swimming research, recommended in the literature.

Starting with physiologists, Costill (1999) pointed out that Olympic swimmers do not distinguish themselves physiologically, it is biomechanics which counts and Holmer (1983) summed up that training develops power, but the swimming speed is determined by technique. In human swimming energy-rate research is not well established like e.g. in studies of swimming animals (Schultz & Webb, 2002). Considering an energy-rate approach might give a better understanding of the interaction of physiological and biomechanical parameters. Bremer (2003) measured oxygen uptake, lactate accumulation and efficiency factors of swimmers and reported that the propelling power of a person amounts to 1800 Watts achieving a speed of approx 1.8 m/s but only 450 Watts for cruising a speed of approx 1.1 m/s. This demonstrates how closely intensity and duration are related, and that speed training, requiring high intensity, short duration and longer rest periods is just part of a continuum of a “power field”.

The studies concerning importance of training volume were also considered. Chartard (1999) reported that swimmers of squads with training loads of 9 km/day do not race faster than squads with 5 km/d. Furthermore those squads which did some seasons at 8 km/d, increased speed in competition. Mujika, Chartard, Busco, Geyssant, Barale, Lacoste (1995) were able to demonstrate that a training regime at high mean intensity over a period of 6 weeks, characterized by exhausting loads between 1 and 2 min accompanied by anaerobic energy release between 60 % to 35 %, will result in a gain of 10
% anaerobic capacity; thus for elite swimmers mean training intensity is the determining component of enhanced performance and not volume or frequency (which might be different in age group swimmers). In addition it was shown that swimmers who improved their performance significantly in a season were primarily those who managed to swim the first races of a new season at relatively higher speed (in % of their personal best). Concerning high intensity training regimes, Costill, Kova-leski, Porter, Kirwan, Fielding, King published already in 1985 that elite athletes might possess a stimulus threshold requiring HIT conditions, resulting in higher power output and faster race times.

The coach also decided to consider this activity as a psycho-physical issue. An activity is a necessary condition which is modulated by personal traits resulting in an internal fatiguing impulse (Mujika, Buss, Geyssant, Chatard, Barale, Lacoste, 1996) and becomes the sufficient determining condition for biological adaptation. Ulmer (1986) pointed out that delayed stress triggers adaptation on the cellular level causing changes in biological mass, like mitochondria, enzymes, vessels, including energy delivery or power systems using existing genetical pathways.

The effect of the daily training routines must not be separated from the daily induced stress of everyday life circumstances, like amount of sleep or psychological stress which may individually influence internal thresholds related to effects of the fatiguing impulse. It was decided to separate training load (strain) from individually perceived effects (stress) and to monitor both aspects for training steering purpose (the saying "no pain no gain" can be understood as the importance of the individual reaction because a given load is not felt to be painful by all members of the squad). The stress level perceived by the athlete can be recorded using a defined scale.

Training documentation formats, used so far, were replaced by a more intelligent format introduced by Mujika et al. (1996), called MITS (mean intensity of a training season). MITS is an easy way to represent training components - intensity, volume and frequency - in a single value instead of data in abundance. Training loads are distinguished in five loading zones which are characterized by established intensity index. MITS is calculated by multiplying the volume data and stress index, respectively, summing up the products – including a dryland training equivalent- and dividing the sum by the total meter sum during the training period taken into consideration. The dryland equivalent was described by Mujika et al. (1996) " … it was empirically considered that 1 h of dryland training was equivalent to 1 km swim at intensity I, 0.5 km at intensity IV and 0.5 km at intensity V." How MITS-level effects the organism is unknown in detail. However, each coach would appreciate when the number of influencing parameters –which are likely to be related to each other in a still unknown way– is reduced.

The purpose of this case study is to report the MITS-values and the perceived delayed stress-values based on being fatigued.

**METHODS**

This is a case study. An elite female swimmer of 14 years of regular training experience and 1:10.57 for 100 m breaststroke gave her consent to document twice a day the perceived level of fatigue a) directly after the workouts and b) on the following morning according to an exhaustion scale. A stress scale was negotiated between coach and athlete before starting the monitoring period. The details were: totally refreshed = 1, recovered = 2 – 3, relaxed = 4 – 5, reposed = 6, flagged = 7, tired = 8 – 9, nervous = 10 –11, exhausted = 12 – 13, sick = 14. The values of i) and ii) were substracted from each other. The difference between both perceived fatigue values was calculated and called delayed perceived fatigue. Over a period of 144 days MITS-values per day were calculated based on the recorded training components; MITS-values are placed between 1 and 3 and values near to 3 represent most straining situations (Mujika et al., 1996). Five intensity zones were defined according to blood lactate and combined with stress index: I1: < 2 mmol/l → 1, I2: 2 mmol/l → 2, I3: 6 mmol/l → 3, I4: 10 mmol/l → 5, I5: sprint → 8. The calculation of MITS as a representative strain factor was as follows.

1. multiply the distance swum per training load zone times the appropriate stress factor
2. convert dry land training duration into stress factor (here a constant factor: 4.5)
3. add (a) 1 + 2 and (b) total training volume (km per day)
4. divide (a) by (b) to get MITS-Values

\[ \text{MITS} = \frac{(n \text{ kmI1}) \times 1 + (n \text{ kmI2}) \times 2 + (n \text{ kmI3}) \times 3 + (n \text{ kmI4}) \times 5 + (n \text{ kmI5}) \times 8 \times 4.5}{\text{total km}} \]

**RESULTS**

The elite female swimmer improved her best time by 2.8 % after this macro cycle over a period of 144 days or 288 half days, respectively. In this case study data of the training components were: training volume = 605 km, training frequency = 188 half days, dryland training = 552 min and 100 half days of rest. The mean distance / day was 3.2 km. The percentages of the total distance covered at each intensity level were: I1 = 13.07 %, I2 = 75.52 %, I3 = 6.38 %, I4 = 1.24 % and I5 = 3.80 %. The calculated MITS-value (mean intensity of a training season) was 2.01 ± 0.12 arbitrary units. For a macro cycle of 16 weeks the distribution of MITS-values per week is presented (Fig 1).

![Fig 1 MITS (mean intensity of a training season) in arbitrary units over a period of 16 weeks; the stars indicate competitions. The representation of weekly MITS-values show a trend towards somehow more intensive training loads.](image)

The data of the perceived status of fatigue recorded directly after all workout sessions were: mean = 6.38 units, SD = ± 1.57 and variance = 2.58 followed the next morning by mean = 5.02, SD = ± 1.97 and variance = 3.90. The differences between the two situations are presented in Figure 2 over 144 days. The level of perceived fatigue after the training sessions is generally higher than the level after sleeping, the morning of the next day, indicating recovery due to rest at night.

![Fig. 2 Perceived delayed fatigue data in arbitrary units over a period of 144 days 0.00 means: no difference between perceived fatigue due to sleeping, minus means: the perceived value after sleeping is lower than after training the day before](image)
Fig. 3. Representation of MITS-values (black lines) per day and delayed perceived fatigue level data (grey lines) over a period of 144 days; stars and grey lines indicate competitions. The mutual representation of daily MITS-values and delayed perceived fatigue show two independent patterns. Delayed perceived fatigue data seem to be more influenced by everyday life circumstances.

DISCUSSION

The last improvement of the personal best happened some years before, while after this macro cycle it was 2.8%. The calculated MITS of 2.01 ± 0.12 units seems to be fairly high when compared to results of 1.53 ± 0.06 units published by Mujika et al. (1996). The MITS-value of this case study indicates a trend towards higher training intensity which was achieved predominantly due to some new methods of dryland training. The work with the dryland-training equivalent approach led to new reflections about the influence of all activities of an athlete on the mental and physical fitness. Treating a dryland training equivalent as a summand of daily training components seems nothing particular; trying to relate this component to training volume is something else. A bridge could be that the organism is not "counting" meters to check the external strain but is internally reacting to intensity over time and the conversion of intensity to volume is like (not similar) converting intensity to power demand.

Especially in swimming, the training of fitness as such is incomplete without shaping the propelling efficiency of each stroke cycle. Consequently the swimmer’s competence to adapt the breaststroke technique to the needs to swim faster was also introduced into the training concept using the approach described by Ungerechts and Schack (1996). Elite swimmers can increase their distance per stroke due to unsteady aspects of the flow around the cruising body (Ungerechts & Klauck, 1996), among others by decreasing a swimmer's active drag.

The selection of the scale for perceived fatigue was installed after the co-workers discussed this issue thoroughly. The daily calculated individual delayed fatigue values were of great value to lower the risk of over training. Especially the athlete appreciated the individualisation of the training regime as a means to trigger adaptation. Recognizing that the recovery from fatigue while sleeping can be expressed in terms of decreasing perceived stress-factors was a challenge. The curves seem to be more influenced by everyday life circumstances. The coach and the athlete had to learn how to reason about the training of a particular person which is always combined with reasoning about individual (expected) properties, traits and personality. A unique tool to improve success is not really known. The question of whether the value can be bettered by sophisticated methods, which was resolved by the fact that the adult swimmer can finally tell best what the needs will be, provided the person can rehearse, is still an open question.

CONCLUSIONS

The new approach intensified the motivation of everybody taking part in this cooperation. Swimming as a techno-motoric sport discipline with a strong psycho-physical endurance component is considered to be a complex sport to deal with. Training frames, -methods and -means should be elements of a systematic concerted intervention which target on fitness, condition, effective strokes and stable mental processes. Monitoring training, including the individually perceived stress levels is a modern approach demanding close cooperation with the athletes because they know best their aims, intentions or how to get involved in the external steering of his/her life (by coaches). Each athlete will react differently to a given training load, based on individual biological factors and on everyday life circumstances. Successful coaches consider this when prescribing various training loads. Although a blueprint telling how much is necessary and sufficient to ensure success is still missing, a better interaction of humans based on certain data will help and is highly recommended.

REFERENCES


Accelerometry as a Means of Quantifying Training Distance and Speed in Competitive Swimmers.

Wright, B.V., Hinman, M.G., Stuger, J.M.

Counsilman Center for the Science of Swimming, Indiana University, Bloomington, IN, USA

The purpose of this study was to examine the potential relationships between accelerometer output (AO) and swim distance (SBD), and AO and swim speed (SBS). Fifty-three competitive swimmers (age: 17.7 ± 3.13 yrs.) were fitted with two accelerometers and completed two swim sets to develop prediction equations for swim bout distance (m) and swim bout speed (ms⁻¹). Significant correlations and regression equations were found for accelerometer output and swim bout distance (Correlation: r = 0.90, R² = 0.81, p < 0.05; Regression: SBD_AO (m) = (AO · .004) + 18.356, r = 0.98, R² = 0.96, SEE = 40.4 m, p < 0.001) and swim bout speed (Correlation: r = 0.80, R² = 0.64, p < 0.05; Regression: SBS_AO (ms⁻¹) = (total combined accelerometer counts per second · .001) + 369, R² = 0.53, SEE = 0.15 ms⁻¹, p < 0.001). A sub-sample the swimmers were used to validate and compare actual and predicted swim distance and swim speed (SBDact vs SBDpred and SBSact vs SBSpred) showed significance (r = 0.97, R² = 0.96, p < 0.001, and r = 0.78, R² = 0.53, p < 0.001 respectively). In conclusion, this study demonstrates that accelerometers have the ability to quantify individual swimming distance and speed with acceptable accuracy and validity.

Key words: Accelerometer, Quantify, Swimming Speed, Swimming Distance

INTRODUCTION

Competitive swim coaches and their respective swimmers are continually challenged to develop and maintain training paradigms over multiple competitive seasons. Successful results from one season to the next are often dependent upon two conditions. The first is that the training sessions elicit an appropriate workload and the second being that the competitive swimmer adheres to these specific workloads. This situation has encouraged many sport scientists to further analyze and quantify competitive training (Hopkins, 1991, Banister and Calvert, 1980, and Mujika et al., 1996). More recently, activity monitors (i.e. accelerometers) have been utilized to analyze arm movement patterns and energy expenditure of competitive swimmers (Ohgi, Y. et al, 2002, and Johnston et al., 2005). The use of accelerometer based activity monitors provides a non-invasive means by which the movement of swimming may be quantified. Therefore, it was the goal of this project to determine whether or not competitive swim training bouts could be quantified after the fact by utilizing available accelerometer technology. More specifically, the purpose of this study is twofold: first, to examine the potential relationships between accelerometer output and swim bout distance, accelerometer output and mean swim bout speed, and second, to compare predicted swim bout distance and swim bout speed (from earlier determined relationships) with that obtained during swims performed during actual observed training sessions.

METHODS

Fifty-three competitive swimmers (33 males and 20 females) were recruited from a local area USA registered swim club to participate in this study. All subjects were registered competitors training with the swim club for one or more years. Their experience levels ranged from beginning level competitive swimmers to US national meet qualifiers. Data collection took place at a 10 lane, 50 m outdoor training facility. Prior to the initiation of the study, the methods and procedures were approved by the University’s Human Subject Committee and informed consent was obtained from each subject or their legal guardian.

The swimmers were fitted with two Actical activity monitors (commercially produced Omni-directional accelerometer; Bend, Oregon) worn on their right wrist and right ankle attached via a modified watch strap. All monitors were placed in the same direction for consistency. An arrow labeled on the surface of the device by the manufacture provided a reference axis for orientation. For placement of the ankle monitor, the monitor was place on the posterior portion of the ankle approximately 5.0 cm above the lateral malleolus with the monitor reference arrow pointing forward. The wrist monitor was placed similar to a watch with the monitor reference arrow pointing in the lateral direction when the subjects’ arm was extended and the palm was facing downward. Monitors were programmed to begin recording at an epoch length of 15 seconds initiated at the onset of the swim session. The study included the assessment of relationships (i.e. correlations), as well as, the development and validation of prediction equations. For the assessment of relationships all subjects (i.e. 53 swimmers) participated in two swim sets using only the freestyle stroke (i.e. front crawl). During the first swim set (Set-A), subjects were given instructions to swim 400, 200, 100, and 50 m swims at a moderate effort. The second swim set (Set-B) included three 50 m swims. In this set swimmers were instructed to complete the first 50 m slow, the second at a moderate pace, and the third at maximal effort. A poolside observer recorded actual distance and the corresponding speed for each subject for each swim performed. Swimming speed was determined via a handheld digital stopwatch (Ultrak model 495). Following data collection Actical activity monitor output (AO) was exported to a Microsoft Excel spreadsheet for each subject and the following Pearson-Product Moment correlations were examined utilizing a single data point from each subject from swim set A and B:

1. AO vs SBD: Total combined (i.e. arm and leg) Actical accelerometer counts and swim bout distance (m).
2. AO vs SBS: Total combined (i.e. arm and leg) Actical accelerometer counts relative to time (counts·second⁻¹) and swim bout speed (ms⁻¹).

For the development phase, linear regression analysis was examined to create descriptive equations for swim bout distance (SBD) and swim bout speed (SBS) using the relationships listed above with a randomly selected swim from swim sets A and B respectively (i.e. Data from 40 subjects). The remaining 13 subjects participated in a separate training session in which a randomly selected swim was used for the validation of the descriptive equations thus permitting their use as prediction equations. Mean differences between actual and predicted swim bout distance (SBDact vs SBDpred) and swim bout speed (SBSact vs SBSpred) were determined using paired samples t-tests and agreements between predicted and measured variables were assessed using the Bland-Altman technique. A significance level of p ≤0.05 was set for all statistical tests. All statistical analyses were conducted using statistical software package SPSS 16.0 (Chicago, IL).

RESULTS

Subject characteristics (displayed in Table 1) did not differ between the regression development group or the validation group.

Table 1. Subject Characteristics (mean ± sd)

<table>
<thead>
<tr>
<th>Subject Characteristics</th>
<th>Subjects (n=53)</th>
<th>Regression Development Group (n=40)</th>
<th>Validation Group (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>17.7 ±3.13</td>
<td>17.6 ±2.84</td>
<td>18.1 ±4.01</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.0 ±9.85</td>
<td>173.6 ±10.20</td>
<td>171.1 ±8.84</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>69.4 ±11.16</td>
<td>70.6 ±10.75</td>
<td>65.75 ±12.10</td>
</tr>
</tbody>
</table>

305
Pearson correlation coefficients examining the relationship between AO vs \( S_{\text{dist}} \) \((r = 0.90, R^2 = 0.81, \text{SEE} = 59.4 \text{m}, p < 0.05)\) and AO vs \( S_{\text{speed}} \) \((r = 0.80, R^2 = 0.64, \text{SEE} = 0.13 \text{m/s}, p < 0.05)\) were both significant. Linear regression analysis for \( SB_{\text{dist}} \) and \( SB_{\text{pred}} \) displayed significant results \( SB_{\text{dist}} (\text{m}) = (AO \cdot 0.004) + 18.356, r = 0.98, R^2 = 0.96, \text{SEE} = 40.4 \text{m}, p < 0.001, \) Figure 1. \( SB_{\text{speed}} (\text{m/s}) = \) (total combined accelerometer counts per second \(- 0.001) + 0.869, R^2 = 0.53, \text{SEE} = 0.15 \text{m/s}, p < 0.001, \) Figure 3.

The validation phase for \( SB_{\text{dist}} \) and \( SB_{\text{speed}} \) prediction equations displayed significant correlations between \( SBD_{\text{act}} \) vs \( SBD_{\text{pred}} \) \((r = 0.97, R^2 = 0.95, p < 0.001, \) Figure 2) and \( SBS_{\text{act}} \) vs \( SBS_{\text{pred}} \) \((r = 0.78, R^2 = 0.61, p < 0.001, \) Figure 4. In addition, a paired samples t-test displayed no significant difference between \( SBD_{\text{act}} \) vs \( SBD_{\text{pred}} \) \((p = 0.904)\) or \( SBS_{\text{act}} \) vs \( SBS_{\text{pred}} \) \((p = 0.727)\). The Bland-Altman plots resulted in no bias for \( SBD_{\text{act}} \) vs \( SBD_{\text{pred}} \) (range limit of 129.5m to 125.1m with a mean of -2.2m) and \( SBS_{\text{act}} \) vs \( SBS_{\text{pred}} \) (range of limit of -0.30m/s to 0.33m/s with a mean of 0.02m/s).

**DISCUSSION**

The present study shows that activity monitors have the ability to quantify the swimming distance and speed of competitive swimmers after completing a competitive training session. Thus, activity monitors provide a useful tool with which the experimenter (or coach) could track the adherence of an athlete to a pre-set training session. It is important to note that accelerometer technology remains a new tool with regard to the quantification of competitive swim training; therefore, very limited literature has documented the use of accelerometers to assess the training distance and speed of competitive swimmers after they have completed their swim session.

Previous studies have included the use of accelerometers to examine swimmers (competitive and recreational) and suggest that accelerometers may also have the ability to estimate swimming energy expenditure (Johnston, J. and Stager, J., 2005), examine swim stroke phases (Ichikawa et al., 1999), and detect fluctuations in performance due to fatigue during a training session (Ohgi, et al., 2002). In addition to the
present data, other recent studies have similarly examined competitive swim training and report encouraging data supporting the further use of accelerometers. For example, preliminary experiments conducted by the Counsilman Center for the Science of Swimming using the Actical activity monitor displayed data that are in support of the relationships between swim bout distance, swimming speed, and accelerometer output reported in the present study (Wright et al., 2007, and Hinman et al., 2008). The current study more thoroughly explored the validity of predicting swim bout distance and swimming speed from accelerometer output. Furthermore, the data from Wright et al. (2007) suggest that when a swimmer is instructed to swim fast, there is a larger contribution from kicking that is evident from the subsequent greater leg accelerometer output. This appears to indicate that in addition to swim speed and swim distance a swimmer’s relative effort from day to day or set to set, might be reflected in the comparative outputs of the appropriately placed accelerometers.

Although, the findings from the current study support the use of accelerometers as a non-invasive means to monitor a swimmer’s adherence to and effort in a competitive swim training session, the application of a single regression equation to predict swimming distance and speed for different types of swimming and or swimmers of different skill levels is limited. It is recommended, albeit more time consuming, to create individual regression equations (e.g. for distance and speed) for each swimmer. This may provide stronger algorithms. In addition the use of an accelerometer with a shorter epoch length would also be ideal. This would produce a greater detailed set of data from which an experimenter or coach may examine training sessions.

In conclusion, this study displayed a significant relationship between swim bout distance, swimming speed, and accelerometer output (i.e. Actical activity monitor). The study also showed that accelerometers have the ability to accurately measure swim bout distance and mean swim bout speed. Future suggestions include the use of accelerometers during actual competition, as well as, the development of computer software that will allow for the immediate display and interpretation of accelerometer output upon the completion of a training session.

REFERENCES

Critical Swimming Speed Obtained by the 200-400 Meters Model in Young Swimmers
Zaca, R.1, Castro, F.A.S.1
1Universidade Federal do Rio Grande do Sul (UFRGS), Brasil.

The aim of the study was to compare the critical swimming speed (CSS) obtained by the 200–400m (CSS10) vs 14 different combinations of CSS and vs 1500m velocity (V1500) in 11 young sprint swimmers (male) of national competitive level. CSS10 (50–100m) was the combination that most overestimated CSS10. The lowest error on the estimation of CSS was observed for the CSS10 (50–400m) (-0.5%) and CSS10 (100–400m) (0.8%). CSS10 underestimated V1500 by 3.5%. This might suggest studies to measure the level of agreement between CSS10 vs the other combinations and between CSS10 vs V1500 to check whether this level of agreement will be maintained until adulthood.

Keywords: Swimming, Performance, Training and Testing, Critical Swimming Speed.

INTRODUCTION
The critical swimming speed (CSS) method has been proposed for predicting swimming training velocity because it is simple and can be applied with several swimmers at the same time during the training sessions. Furthermore, the CSS is an attractive tool to assess the evolution or that occurs with training in a given period of time (VILAS-BOAS et al. 1997). CSS obtained from the modeling of the distance-time relationship using the two-parameter model is defined as the angular coefficient of the linear regression between the distance (x axis) and the time (y axis) of different swimming distance trials (Ettema, 1966). CSS represents the highest intensity that is sustainable for a prolonged duration, without eliciting maximal oxygen uptake (VO2max), i.e. the lower boundary of the severe intensity domain (Dekkerle et al., 2008). CSS has been defined based on different sets of race distances (Dekkerle et al., 2002; Wakayoshi et al., 1992b, 1993; Wright and Smith, 1994). However, previous research showed that different combinations of distance can result in different CSS (Greco et al., 2003) because of the “aerobic inertia” (Wilkie 1980; Vandewalle et al. 1989), related to the cardiorespiratory tuning to the oxygen uptake which reaches its steady or maximal state. In addition, predicting CSS from the 200 and 400-m swimming performances were proposed as optimal for swimming training (Wakayoshi et al., 1993; Dekkerle et al., 2002) with a prediction of the “onset of blood lactate accumulation” (OBLA) of +3.3% (Wakayoshi et al., 1993) (Heck et al., 1985) and +3.2% higher when trying to predict the velocity over a 30-min test (Dekkerle et al. 2002). Moreover, several studies have focused on the comparison between CSS obtained from the 200 and 400-m combination (CSS10) and other combinations of race distances to predict CSS in young swimmers. Regardless of the distances swum, the ability to calculate values of CSS obtained with performances in competition could make the CSS an even more attractive tool for coaches and swimmers. Having access to information of possible differences between CSS10 and other combinations for predicting CSS seems important when for some reason the coach needs to calculate the CSS with other distances. Thus, coaches could make the necessary corrections to obtain CSS values of the combination of 200–400m and use it in the training prescription. The primary aim of the present study was to compare CSS using the 200 and 400-m race distance with another 14 combinations of distances ranging from 50 m to 1500-m in young swimmers. The secondary aim was to compare these CSS with the 1500-m best performance velocity (V1500).

METHODS
Participants: 11 young sprint swimmers (male) of national competitive level (Age: 14.4 ± 0.5 years old; Body Mass: 60.6 ± 7kg; Height: 175 ±
Comparing the proposed combinations used in this study with CSS₁₀, CSS₇, and CSS₁₄ showed the highest difference (p = 0.0004) and worst level of agreement (-0.119 m·s⁻¹; -8.9%). The lowest error on the estimation of CSS was observed from CSS₇ (-0.005 m·s⁻¹; -0.5%) and CSS₁₀ (0.010 m·s⁻¹; 0.8%) both including the 400-m trial in their calculation. Furthermore, the limits of agreement were very similar (CSS₇: -6.1 to 5.1%; CSS₁₀: -5.0 to 6.6%). CSS₁₅ overestimated V₁₅₀₀ by +3.5%.

**DISCUSSION**

The method used to calculate CSS (two-parameter model) has many advantages as a) ease of application, b) analysis of large numbers of athletes can be carried out during training sessions without the use of expensive equipment or blood collection, and c) easy to assess the evolution or that occurs with training in a given period of time. This eases the testing, especially for swimmer populations such as children and adolescents. Having access to information of possible differences between CSS₁₀ and other combinations for predicting CSS seems important when for some reason the coach needs to calculate the CSS with other distances.

The first result of the present study was that the highest difference recorded in this study was that between CSS₇ and CSS₁₁. However, a level of agreement is a more sensitive tool for testing the accuracy of a method to predict a single parameter. The substantial contribution of the anaerobic metabolism in the 50 and 100-m races (Gastin, 2001) could explain this high difference between CSS₁₀ and CSS₇ (bias: -0.119 m·s⁻¹; -8.9%).

The lowest error in the estimation of CSS₇ was observed for CSS₁₀ (-0.005 m·s⁻¹; -0.5%) and CSS₁₀ (0.010 m·s⁻¹; 0.8%) both of them including the 400-m performance and one short distance (50 or 100-m) in the modeling. In addition, the limits of agreement were very similar (CSS₇: -6.1 to 5.1%; CSS₁₀: -5.0 to 6.6%). Gastin (2001) used mathematical modeling techniques and suggested that performances lower than 75 s (under maximal intensity) need more contribution of anaerobic than aerobic metabolism. However, there is a lower concentration of glycolytic enzymes and an increased concentration of aerobic enzymes in adolescents compared with adults. Adolescents have a lower concentration of steroid hormones, which will increase with the maturation process and therefore increase muscle mass and anaerobic capacity (Dipla et al., 2009). Thus, probably the low anaerobic capacity of the swimmers is responsible for the similarity between CSS₁₀, CSS₇ and CSS₁₁ because the distances of 50 and 100-m do not seem to have increased the value of CSS obtained by CSS₇ and CSS₁₀. For females, it has been observed that muscle power reaches an earlier steady state, i.e. soon after 14-15 years (Dipla et al., 2009). This might suggest studies to measure the level of agreement between CSS₁₀ and the other combinations in young female and male swimmers (14-15 years), also to check whether this level of agreement will be maintained until adulthood.

Third, the results showed that the level of agreement between CSS₁₀ and the combinations that use the distance of 800-m, 1500-m or both, can underestimate CSS₁₀ in young swimmers. In our study, the underestimation of CSS₁₀ was established between -3.3 to 6.5%. The greater contribution of aerobic metabolism of the total energy required to travel distances of 800 and 1500-m (800-m: 643.5 ± 36.75 s, 1500-m: 1231.9 ± 88.58 s) seems to have been the main reason for these findings (Gastin, 2001). In addition, although they are swimmers with a considerable level of experience, the application of extensive tests (800 and 1500-m) in young swimmers in the swimming training situation rather than a competitive situation may diminish their motivation which would affect the performance of the test. Moreover, as they are sprint swimmers, some of them probably did not have sufficient experience with longer events.

Finally, CSS₁₅ (200-400m) was higher than V₁₅₀₀ (+3.5%) with performances over this distance ranging from 19.5 to 22-min (1231 ± 88 s) in young swimmers. This difference was similar to that found between CSS₁₁ and the speed of 30-min test by Dekker et al. (2002), which suggested a correction of -3.2% to establish the swimming velocity over

### RESULTS

Mean and standard deviation of performance time (s) in each distance are shown in Table 1. The results of comparisons between CSS₉ and the other predictions with V₁₅₀₀ are shown in Table 2.

#### Table 1: Mean and standard deviation of performance time (s) for each distance (50, 100, 200, 400, 800 and 1500-m).

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Mean (s)</th>
<th>SD (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>29.36 ± 1.67</td>
<td>65.64 ± 3.50</td>
</tr>
<tr>
<td>100</td>
<td>146.55 ± 7.57</td>
<td>305.09 ± 16.65</td>
</tr>
<tr>
<td>200</td>
<td>643.55 ± 36.75</td>
<td>1230.91 ± 88.58</td>
</tr>
<tr>
<td>400</td>
<td>1113.01 ± 68.36</td>
<td></td>
</tr>
</tbody>
</table>

#### Table 2: Comparison between CSS₉ with the other predictions and V₁₅₀₀ by the t-test and the level of agreement expressed in absolute and percentage results.

<table>
<thead>
<tr>
<th>CSS Combination</th>
<th>T-test Significance</th>
<th>Bias (1.56 SD)</th>
<th>Agreement (absolute and percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSS₉ (100-200 m)</td>
<td>p &lt; 0.05</td>
<td>-0.008 (0.02)</td>
<td>+0.06%</td>
</tr>
<tr>
<td>CSS₉ (100-200 m)</td>
<td>p &lt; 0.05</td>
<td>-0.008 (0.02)</td>
<td>-0.01%</td>
</tr>
<tr>
<td>CSS₉ (100-200 m)</td>
<td>p &lt; 0.05</td>
<td>-0.008 (0.02)</td>
<td>+0.06%</td>
</tr>
<tr>
<td>CSS₉ (100-200 m)</td>
<td>p &lt; 0.05</td>
<td>-0.008 (0.02)</td>
<td>-0.01%</td>
</tr>
<tr>
<td>CSS₉ (100-200 m)</td>
<td>p &lt; 0.05</td>
<td>-0.008 (0.02)</td>
<td>+0.06%</td>
</tr>
<tr>
<td>CSS₉ (100-200 m)</td>
<td>p &lt; 0.05</td>
<td>-0.008 (0.02)</td>
<td>-0.01%</td>
</tr>
<tr>
<td>CSS₉ (100-200 m)</td>
<td>p &lt; 0.05</td>
<td>-0.008 (0.02)</td>
<td>+0.06%</td>
</tr>
<tr>
<td>CSS₉ (100-200 m)</td>
<td>p &lt; 0.05</td>
<td>-0.008 (0.02)</td>
<td>-0.01%</td>
</tr>
<tr>
<td>CSS₉ (100-200 m)</td>
<td>p &lt; 0.05</td>
<td>-0.008 (0.02)</td>
<td>+0.06%</td>
</tr>
</tbody>
</table>

Note: * = p < 0.05
a 30-min test by the CSS_{10} in adult male swimmers (18.6 ± 1.9 years). Studies also found that the speed of a 20-min test in adolescents or a 2000-m test in adults was similar to the speed at Lactate threshold (Greco et al., 2003; Matsunami et al., 1999). However, further studies are needed to check whether or not it would be erroneous to use a single correction factor to predict the velocity over a 30-min test or V_{1500} through CSS_{10} both in adolescence and adulthood, as these differences seem to vary during the development of swimmers (Dipla et al., 2009).

**CONCLUSION**

CSS (50-100m) was the model that most overestimated CSS_{10} (200-400m). The lowest error in the estimation of CSS_{10} was observed with CSS_{v0} (0.5%) and CSS_{v1500} (0.8%). CSS_{10} overestimated CSS_{v1500} by +3.5%. CSS_{10} (200-400m) was higher than V_{1500} (+3.5%) with performances over this distance ranging from 19.5 to 22-min (1231 ± 88 s) in young male swimmers. Having access to information of possible differences between CSS_{10} and other combinations for predicting CSS seems important when for some reason the coach needs to calculate CSS with other distances. It might suggest studies to measure the level of agreement between CSS_{10} and the other combinations and between CSS_{0} and V_{1500} to check whether this level of agreement will be maintained until adulthood.

**REFERENCES**


**ACKNOWLEDGEMENT**

The authors would like to thank Cristiano Klaser, Ricardo Peterson Silva and Rodrigo Bini for their involvement in this study.
Chapter 5. Education, Advice and Biofeedback
The aim of this study was to analyze the evolution of swimming science research based on the content analysis of the “Biomechanics and Medicine in Swimming” Proceedings books from 1971 to 2006. The content of all the 622 papers published in the proceedings books of the “International Symposium on Biomechanics and Medicine in Swimming” series edited from 1971 to 2006 were analyzed. An observation grid for the manuscript analysis was developed. This instrument was composed by observational categories previously defined by the researchers. Two main categories were defined: (i) the “aquatic activity” studied in each paper analyzed and; (ii) the main “scientific area” applied for the assessment.

The main category “aquatic activity” included the following sub-categories: (i) Competitive swimming; (ii) Water Polo; (iii) Synchro-nized Swimming; (iv) Diving; (v) Hydrotherapy; (vi) Infant Swim; (vii) Head-out Aquatic Exercises; (viii) Fin Swimming and; (ix) others. The main “scientific area” included the following sub-categories (adapted from Clarys, 1996): (i) Biomechanics; (ii) Psychology; (ii) Sociology; (iii) Pedagogy/Teaching; (iv) Biochemistry; (v) Physiology; (vi) Thermoregulation; (vii) Hydrodynamics; (viii) Electromyography; (ix) Anthropometry; (x) Equipment/Methodology; (xi) Clinical Medicine/Traumatology and; (xii) Interdisciplinary assessment.

For identification of each sub-category the following steps were used: a) read the abstract, identifying the aquatic activity studied, as well, the scientific area of assessment; b) whenever necessary or appropriate read the full paper; c) if the paper was not able to be inserted in any of the sub-categories defined for the main category “aquatic activity” it would be identified as “others” (e.g., life saving, recreational games, etc).

The absolute frequency for the number of papers in each edition of the proceeding s was registered. Relative frequency for each subcategory in a given edition and for full period of time between 1971 and 2006 was considered.

RESULTS
Figure 1 presents the number of papers published between 1971 and 2006. There was an increasing number of papers published within the period of time analyzed (ranging from 23 papers in 1971 to 145 manuscripts in 2006). The only exception to the increasing trend was the 1996 edition.

Figure 1. Evolution in the number of papers published between 1971 and 2006.
Figure 3 presents the evolution in the relative frequency of each sub-category within the 1971-2006 time frame. About the “scientific area” it is possible to verify that at any given moment there is a major interest about one or a couple of specific issues, besides “Biomechanics” and “Physiology”. For example, in 1983 there were several papers published about “Hydrodynamics”, in 1988 “Biochemistry”, in 1992 “Anthropometry” and in 2006 “Interdisciplinary assessment”. For the “aquatic activity” “Competitive swimming” was always on top. However, starting in 1999 there was an increasing interest for “Head-out aquatic exercises” and “Fin swimming”.

DISCUSSION
There was an increasing number of papers published within the period of time analyzed (ranging from 23 papers in 1971 to 145 manuscripts in 2006). So, “swimming science” seems to be increasing since 1971, as the number of research groups focused in this sport is increasing, as well as, the number of research projects developed by each group. The 1996 book was the only one that did not present a greater number of papers in comparison to the previous edition. From the 80 studies presented at the VIIth Symposium on Biomechanics and Medicine in Swimming, only 36 were selected to be published. This means that from the 1992 edition (with 64 papers published/presented) to the 1996 edition there was actually an increase in the number of studies presented.

Comparing the sub-categories related to “Aquatic activity” the one with most research conducted was clearly “Competitive swimming” (ranging from 78.8 % in 1971 to 100 % in 1996). In the last decade there is a slight but increasing interest in “Head-out aquatic exercises” (e.g., the second most studied aquatic activity in 2006 with 6.9 %). Aquatic activity was for a long time synonymous with swimming. Added to this, “Water polo” was also specially under the BMS scope, as is verified by the name of the 1971 proceeding book: “First International Symposium on Biomechanics in Swimming, Water Polo and Diving”. Nowadays “Head-out aquatic exercises” are gathering a large part of the persons practicing physical activity in aquatic centres. Indeed, these facilities provide services that are complementary to “traditional” competitive sports, such as “Head-out aquatic activities”. This is related to the increasing importance of aquatic activity for health. Starting in 1999 there was also an increasing interest in “Fin swimming”. “Fin swimming” now has a more consistent position among the aquatic competitive sports. “Fin swimming” has competitions at all levels, including international and media attention is increasing in some countries.

Analyzing the main “scientific area” of study, “Biomechanics” was the most common area (ranging from 27.3 % in 1988 to 60 % in 1979), followed by “Physiology”. As “Biomechanics” and “Physiology” were within the origins of this scientific meeting, it is logical that they are the largest sub-categories. It is consensual that biomechanical and physiological profiles of a swimmer are determinant factors for his/her performance enhancement. Since 2003 an increasing trend in “Interdisciplinary assessment” manuscripts is verified. There is now a trend to understand not only how each scientific area determines performance, but also how they interplay. At certain periods of the history of BMS the major area of interest in addition to “Biomechanics” and “Physiology” (e.g., in 1983 the “Hydrodynamics”, in 1988 the “Biochemistry”, in 1992 the “Anthropometry” and in 2006 the “Interdisciplinary assessment”). It seems there are some topics that are deeply explored in a given moment by several research groups.

CONCLUSION
As a conclusion, there is a significant increase in scientific production regarding aquatic activities throughout the 1971-2006 period. Concerning the scientific area the main interests are related to “Biomechanics” and “Physiology”. Recently there is a trend in “Interdisciplinary assessment”. “Competitive swimming” is the main aquatic activity studied. In the last proceedings, the tendency for a higher interest in “Head-out aquatic activities” was verified.

REFERENCES

ACKNOWLEDGMENTS
Ana M. Cruz would like to acknowledge the Portuguese Science and Technology Foundation (Research Integration Grant BII - CIDESD/UTAD).
Quantitative Data Supplements Qualitative Evaluations of Butterfly Swimming
Becker, T.J.1, Havriluk, R.2

1Everett Pacific Industrial Rehabilitation, Seattle, USA
2Swimming Technology Research, Tallahassee, USA

As mechanical advantage increases with both shoulder extension and elbow flexion during the beginning of the butterfly pull, it was hypothesized that hand force would significantly increase with two events: 1) when the hands first submerge below the level of the shoulders and 2) when elbow flexion begins. Female swimmers (n = 23) from three university teams were tested with Aquanex+Video swimming butterfly over a 20 m course. As hypothesized, there was a significant (p<.01) increase in force for both events, emphasizing the importance of a mechanically advantageous angle at both the shoulder and elbow. Based on the quantitative results, coaches can qualitatively evaluate swimmers to ensure they eliminate the wasted time that their hands are above the shoulders and begin elbow flexion as soon as the arm entry is complete.

Key Words: technique, biomechanics, hand force, quantitative, qualitative, analysis

INTRODUCTION
Previous analyses of thousands of trials of synchronized underwater video and hand force data (e.g. Havriluk, 2006a, 2010) show a dramatic increase in force at the beginning of the butterfly pull immediately following two events: 1) when the hands first submerge below the level of the shoulders and 2) when elbow flexion begins. As both of these events are usually observable by a coach on the pool deck, quantitative data about these events may help coaches to better qualitatively assess technique.

As the mechanical advantage increases with both shoulder extension and elbow flexion at the beginning of the pull, it is hypothesized that hand force will significantly increase with these events. Since hand force is directly related to swimming velocity, it is vital that swimmers capitalize on events that increase hand force. In addition to the potential performance benefits from technique adjustments designed to improve mechanical advantage, it is even more important to avoid mechanically disadvantageous positions that often stress the shoulder. The purpose of this study was to quantitatively determine key events in the initial phase of the butterfly pull that a coach can qualitatively evaluate and modify to improve performance and reduce the onset of injury.

METHOD
Female swimmers (n = 23) from three university teams were tested with Aquanex+Video swimming butterfly (Figure 1). The standard Aquanex testing protocol as described in previous research (e.g. Becker & Havriluk, 2006; Havriluk, 2003, 2004, 2006b) was used. Sensors were positioned at the center of the swimmer’s hand between the third and fourth metacarpals to measure the pressure differential between the palmar and dorsal surfaces. The sensor and video output were connected to a computer via an interface on the pool deck. Underwater video and force data were collected over the last 10 m of each trial. Informed consent was obtained. The descriptive statistics were: height in cm (M = 165, SD = 6.7) and mass in kg (M = 62.7, SD = 7.6).

RESULTS
There was a significant (p<.01) increase in force for two events: when the hands first submerged below the level of the shoulders and when elbow flexion began (Table 1 and Figure 3). There was no significant change in force when the hands first became medial to the elbows or when the hands passed perpendicularly below the shoulders. The swimmers required .35 sec (SD = .11) to submerge the hands below shoulder level out of the .82 sec (SD = .12) of the total time that the hands were underwater generating force.
A review of the temporal sequence of two key events prompted a post hoc analysis. About half of the swimmers initiated elbow flexion as the hands submerged below shoulder level and about half after. The swimmers were stratified according to the temporal order of these two events and the average hand force before and after the hands submerged below shoulder level was calculated. The swimmers who initiated elbow flexion after the hands submerged below shoulder level (n = 11) increased force by 12.9 N (.9σ). Swimmers who initiated elbow flexion as the hands submerged below shoulder level (n = 12) increased force by 22.5 N (2.0σ).

**DISCUSSION**

The analysis has kinetic, kinematic, and anatomical components. The data for all three components support the value of similar technique elements that can be qualitatively evaluated.

As far as kinetics, the large increases in force when the hands first submerged below the level of the shoulders and when elbow flexion began emphasize the importance of a mechanically advantageous angle at both the shoulder and elbow. The importance of mechanical advantage is further supported by the fact that the subgroup of swimmers who initiated elbow flexion before the hands submerged below shoulder level increased force by twice as much as the swimmers who initiated elbow flexion after that event.

The kinematics also provide data for technique evaluation. Over 40% of the time that the swimmers' hands were generating force, the hands were above the level of the shoulders (i.e. posterior to the frontal plane). This is an extremely large proportion of the stroke cycle for the arms to remain in a mechanically disadvantageous position. For example, the swimmer in Figure 4 wasted almost .4 sec before the hands submerged below shoulder level.

Figure 4. Aquanex+Video example of wasted motion with the arms and head in a mechanically disadvantageous position.

Anatomically, the disadvantageous position of the shoulders in the initial phase of the butterfly (Figure 4) is due to internal rotation of the humeral head, placing the greater tuberosity in close contact with the undersurface of the acromion. The resulting position is classically related to joint surface aggravation or “impingement syndrome” (Becker, 1986). Any increased time of compressive joint loading between the humerus and acromion (such as the .35 sec found in the study) presents potentially injurious joint surface irritation. Thus, with ideal stroke mechanics in the butterfly not only does the efficiency of the stroke improve, but there is also a reduction in joint surface compression exposure.

The kinetic, kinematic, and anatomical findings all support an arm entry that positions the arm in a mechanically advantageous position. A downward entry angle will result in a relatively strong arm position at...
the completion of the entry phase (Figure 5). While these adjustments are primarily designed to avoid shoulder injury and increase average hand force, stroke rate will also increase. Once the entry is complete, elbow flexion can immediately begin.

The lack of significant increase in force for two of the key events can be explained. The angle at the elbow was already 90° when the hands became medial to the elbows, so no force increase due to mechanical advantage could be expected. When the hands passed perpendicularly below the shoulders, any potential increase in mechanical advantage is tempered by a slowdown in hand speed due to the change in muscle-ture from pulling to pushing (Richardson, 1986).

Logistics often make it difficult for a coach to collect quantitative data on technique during a training session. Qualitative observations to determine when the hands submerge below the level of the shoulders and when elbow flexion begins, however, are entirely possible. Tracking these two events is critical to minimize the time that the arms are in a position likely to stress the shoulders and maximize the time that the arms are in a mechanically advantageous position for force generation.

CONCLUSION

Based on the quantitative results, coaches can qualitatively evaluate swimmers to ensure they eliminate the wasted time that their hands are above the shoulders at the beginning of the butterfly pull by adjusting the entry angle. A downward entry angle will result in a stronger arm position, a faster stroke rate, and less shoulder stress. Coaches can also encourage swimmers to begin elbow flexion as soon as the entry is complete. In addition to improving performance, these technique adjustments will be helpful in reducing the onset of shoulder injury.

REFERENCES


The Effect of Restricting the Visual Perceptual Task in the Temporal Organization of Crawl Swimming: Surface Characteristics

Brito, C.A.F. ¹, Belvis, W.C. ², Oliveira, M. ²

¹ Municipal University of São Caetano do Sul (USCS), São Caetano do Sul, Brazil
² Competitive Team DETUR, São Caetano do Sul, Brazil

The objective of this study was to observe how disturbing swimming skill execution can influence the superficial parameters of front crawl. There was mixed random-systematic sampling among 5% of high-ability swimmers from São Caetano do Sul, enrolled with DETUR in 2008 (n=106). Disturbance was carried out by light shone onto the retina, forming a configuration according to the degree of complexity. The subjects swam at a natural rhythm. Data were analyzed using Mauchly's Test of Sphericity and repeated measures ANOVA (Contrast). Probability was 5% (p<0.05). We observed significant differences (p<0.05) in the variable parameters (time, speed, distance and swimming strategy) of front crawl after perception manipulation, even when maintaining the distance to be executed and a normal swimming rhythm.

Key words: restricting, perception, synchronization, swim, temporal organization

INTRODUCTION

Research on behaviour, especially concerning motor control, has focused on how temporal organization occurs, in motor abilities. There has been an attempt to understand this structure and to find out the nature of its representations, in changeable (e.g., surface characteristics) and unchangeable aspects (e.g., deep structure) (Manoel & Connolly, 1995; Xavier Filho & Manoel, 2002; Schmidt & Wisberg, 2001).

Examining these aspects, several studies have manipulated certain flexible parameters of movement (distance; speed; strength; mass; amplitude), and have verified that there are, in its structure, aspects that remain constant (e.g., relative temporal organization) (Freudenheim et al., 2005; Xavier Filho & Manoel, 2002). However, to our knowledge, no study manipulated perception, keeping surface characteristics constant (Brito, 2008). Thus, the aim of this study was to verify whether there are differences in variable parameters of crawl, after disturbing the visual field of the task (e.g., visual demand), maintaining swimming rhythm and distance.

To understand how it is possible for the swimmer to acquire new patterns in swimming skills, it is necessary to understand the concept of restriction. Restriction is defined as a factor which may determine phenomenal behaviour, because every action is acquired and synchronized within a restriction set. This restriction set may come from geographical elements (e.g., environment), from the organism (e.g., swimmer) or from the task (e.g., swimming itself). Restriction must be considered as the limits or conditions imposed on the swimmer, leading to synchronization of the movement. Figure 1 shows an outline of the role of restriction on swimming.

METHODS

The study was approved by the ethics committee of University of Santo Amaro, São Paulo, Brazil. This was direct research, using descriptive (emphasizing exploratory) and experimental methods.

The subjects were systematically and randomly assigned and gave written consent to take part in the study. Six swimmers, representing 5% of high ability (National and International Competitive Level) swimmers from São Caetano do Sul, enrolled with DETUR in 2008 (n=106).

We used a Seiko chronometer, with 100 memories, to register time taken to swim 25 meters and filmed the task (Sharp, VL-AH131U, Hi 8, 14.345 MS, model power zoom 16x). Information about the subjects (name and group) was registered on a card. Information about the task was also registered on a card (water temperature, date of the test, volunteer number and name, time to perform the task, number of strokes and other issues, when necessary).

The subjects swam front crawl throughout the 25 meters, in a natural rhythm, having a break after all had finished the task. The swimmers started at the command of the researcher.

To disturb swimming synchronization, the light sent to the retina received a configuration according to the degree of complexity. Complexity was related to the restriction of light by occluding goggles with paper, as described below. Each volunteer experienced the same restriction of light, every moment, on six attempts. The disturbance used in this study design was as follows:

- Without restriction;
- Blinded, lower field;
- Blinded, upper field;
- Completely blindfolded on the dominant side, but breathing on the opposite side;
- Blindfolded, but keeping a small opening (foramen) – with convergence;
- Blindfolded, but keeping a small opening (foramen) – with divergence

For statistical analysis, parametric statistics was used, after determining normality by the Kolmogorov-Smirnov test. Data were analyzed by Mauchly's Test of Sphericity and ANOVA was used for repeated measures (Contrast). If the interaction effect was significant, the effect of each main factor was analyzed by contrasts within of the levels of the other factor. Data were analyzed by using the program SPSS (version 13.0), and P values<0.05 were considered as significant.

RESULTS

We observed significant differences in the independent parameters of front crawl after perception manipulation, even when keeping swimming distance and considering a normal swimming rhythm. Upper field, foramen convergence and foramen divergence presented higher values...
for time, when compared to without restriction (21.68±2.69; 21.51±2.5; 22.73±3.31 s vs. 20.33±1.92 s, respectively) and lower values for speed, when compared to without restriction (1.17±0.15; 1.18±0.14; 1.12±0.15 m·s⁻¹ vs. 1.24±0.12 m·s⁻¹, respectively, p<0.05). No significant differences were observed in stroke frequency due to restrictions (Without Restriction - 0.93±0.08; Lower Field - 0.9±0.08; Upper Field - 0.89±0.09; Breathing Against - 0.89±0.10; Foramen Convergence - 0.91±0.10; Foramen Divergence - 0.90±0.10 s·s⁻¹, respectively, p<0.05). All results are presented on Table 1, following the sequence of the experiment.

Table 1. Time, Speed, Strokes Frequency (SF), Strokes Length (SL) and Swimming Strategy (SS = SF·SL⁻¹) responses, related to the restriction imposed, on 25 meters of front crawl, at a natural rhythm. Data are expressed as the mean value ± SD.

<table>
<thead>
<tr>
<th>Without Restriction</th>
<th>Lower Field</th>
<th>Upper Field</th>
<th>Breathing Against</th>
<th>Foramen Convergence</th>
<th>Foramen Divergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (s)</td>
<td>20.33±1.92a</td>
<td>20.69±2.33b</td>
<td>21.68±2.69</td>
<td>21.08±2.06</td>
<td>21.51±2.54±</td>
</tr>
<tr>
<td>Speed (m·s⁻¹)</td>
<td>1.24±0.12b</td>
<td>1.22±0.14b</td>
<td>1.17±0.15</td>
<td>1.2±0.12b</td>
<td>1.18±0.14b±</td>
</tr>
<tr>
<td>SF</td>
<td>0.93±0.08</td>
<td>0.9±0.08</td>
<td>0.89±0.09</td>
<td>0.89±0.10</td>
<td>0.91±0.10±</td>
</tr>
<tr>
<td>SI (m)</td>
<td>1.34±0.15</td>
<td>1.36±0.13</td>
<td>1.33±0.20</td>
<td>1.36±0.23</td>
<td>1.31±0.21</td>
</tr>
<tr>
<td>SS (SF·SL⁻¹)</td>
<td>0.70±0.12</td>
<td>0.67±0.09</td>
<td>0.68±0.13</td>
<td>0.68±0.17</td>
<td>0.71±0.16</td>
</tr>
</tbody>
</table>

(a = p<0.05) Significantly different from “Without Restriction”; (b = p<0.05) Significantly different from “Foramen Divergence”.

DISCUSSION
In this study, the results show that there are significant differences (p<0.05) between front crawl independent parameters (time, speed, stroke length and swimming strategy) after manipulation of visual perception, even maintaining the same environment (distance of 25 meters) and swimming at a natural rhythm, confirming our experimental hypothesis.

There were no significant differences (p>0.05) in stroke frequency, which remained constant for all type of restrictions. This may have occurred because high ability swimmers don’t change their structure of swimming, maintaining the rhythm, due to their conscious perception of the environment (capacity of determining parameters) (Brito, 2008). Foramen divergence was the restriction that showed the highest significant differences (p<0.05) from the other type of restrictions on flexible parameters of front crawl.

After finishing the experimental protocol, it was observed that there is an order of perceptual functional power in the field, according to the type of restriction, going from higher stability to higher instability (0 - Without restriction; 1 - Lower field; 2 - Upper field; 3 - Breathing against; 4 - Foramen convergence; 5 - Foramen divergence).

Concerning synchronization (e.g., movement control), the results of this study corroborate the idea that front crawl temporal organization, in its variable aspects, depends on the perceptual structure (e.g., Visual field), and, so, it exerts its function in perceptual representation in a conscious manner, different from data shown by other studies on motor behavior (Manoel & Connolly, 1995; Xavier Filho & Manoel, 2002; Schmidt & Wisberg, 2001; Freudenheim et al., 2005).

This may, in part, be explained because the theoretical orientation of this study came from Gestalt theory (Koffka, 1927), which explains behavior not as elements in a hierarchy but as a Gestalt quality (Brito, 2008).

CONCLUSION
Other studies are needed to verify whether unchangeable aspects remain constant, even when managing perception.

In Gestalt theory, there is an assumption that, given the conditions of the proximal stimulus (Sensory aspects - changeable) the distal stimulus (perceptual aspects - unchangeable) modifies with every change in the proximal stimulation.
Analyses of Instruction for Breath Control While Swimming the Breaststroke

Hara, H.1, Yoshioka, A.2, Matsumoto, N.2, Nose, Y.2, Watanabe, R.1, Shibata, Y.1, Onodera, S.2

1 Kokugakuin University, Faculty of Human Development, Yokohama, Japan
2 Kawasaki University of Medical Welfare, Kawasaki, Okayama, Japan
3 Tourism University, Faculty of Literature, Saitama, Japan
4 Tokyo Gakugei University, Department of Sports & Health Science, Tokyo, Japan

The purpose of this research was to clarify the important factors preventing swimming apnea. We conducted the experiment with seven subjects using four pressure transducers simultaneously. These were connected to the control unit and the data were analyzed to detect pressure changes with the face in three different positions. We verified that trained swimmers vary the amount of air blown out of the nose and mouth independently. There was an interval between exhaling from the nose to exhaling from the mouth. In the case of instruction for beginners, in order to prevent swimming apnea it is effective if the instructor has the learner pronounce “Mmu” with the nose, then once that is completed, pronounce “Pha” or “Pa” from the mouth to blow out.

Key words: swimming apnea, inhalation, nasal pressure, pronunciation, oral pressure

INTRODUCTION

One of the difficulties while developing swimming technique is how to control breathing. Breath control is important for the acquisition of swimming skills such as stroke movement of arms and legs, and swimming faster in the various swimming strokes.

However, it is not clear what the trigger for inhalation is while swimming. In the exhalation phase, water pressure helps exhalation. Otherwise, inhalation is more arduous than on land because water pressure works to resist the enlarging of chest volume. Even trained swimmers occasionally take in water during inhalation while swimming. Why are these kinds of mistakes occurring?

It is the purpose of this study to clarify the important factors preventing swimming apnea, or the unintentional water-blockage of the airways.

METHODS

The design of this experiment was approved by the Department of General Planning, Research Cooperation Section of Kokugakuin University. We explained the purpose and methods of this study to the subjects in verbal and written form, and informed consent was obtained from all the subjects. The seven subjects who voluntarily participated in this study were healthy university students; four students were trained in swimming but all. The seven subjects who voluntarily participated in this study were healthy university students; four students were trained in swimming but we measured nasal cavity and oral cavity pressure while simulating the breaststroke motion, using four pressure transducers (SPC-464; Miller Instruments) simultaneously. These were connected to the control unit (TCB-500; Miller Instruments) by cables (TEC-10D; Miller Instruments). The equipment had been tested and verified in earlier work (3). One transducer was placed just beside the nose to measure water depth pressure at the nostril level (Channel: 1). The second was inside the nasal passage for measuring nasal cavity pressure (Ch: 2). The third was placed on the cheek at the level of the mouth to measure water depth pressure at this level (Ch: 3). The fourth was placed in the mouth for measuring oral cavity pressure (Ch: 4). Data were recorded on LogWorx (Distributed Design Corporation) program with the Recorder (EFA400; Distributed Design Corporation).

The data were analyzed to detect the pressure changes in three positions of the face. Position 1: Nose above the water surface but the mouth was in the water. Position 2: Nose and a mouth were both immersed in water. Position 3: Face was rising up and immersing down into water, simulating swimming the breaststroke.

RESULTS

Position 1: The nasal pressure and oral pressure did not change at the same time in the case of exhalation except for one subject, who was not a skilled swimmer. His nasal pressure changed with oral pressure. But after blowing out from the mouth in the water, almost all nasal pressures rose momentarily.

Position 2: In the case of strong exhaling from the nose, the nasal pressure and oral pressure changed simultaneously. On the other hand, at the moment of strong exhalation from the mouth, the nasal pressure did not elevate. (Fig.1)

Figure 1. The data obtained from Position 2: At the moment of strong exhalation from the mouth, the nasal pressure (Ch2) did not rise. In this experiment, the pressure curves were not correlated between nasal and oral spaces (Ch4).

Position 3: We verified, using pressure sensors attached simultaneously in nose and mouth, that trained swimmers vary independently the amount of air blown out of the nose and mouth airways. There was some time-lag between exhaling from the nose to exhaling from the mouth, and this occurred while swimmers were face up above the surface of the water. In Position 3, the end of positive oral pressure was delayed 0.38sec. (Average) from the end of nasal positive pressure in trained subjects, and in untrained subjects, the delayed time was 0.11sec. (Ave.).

Figure 2. The data obtained from Case.3 (Simulation of breaststroke swimming) in this experiment by the trained subject. The nose was rising from water surface just before the mouth. After the nose has risen, delayed exhalation from the mouth was observed (Ch4), and nasal pressure (Ch2) did not retain high values.
**DISCUSSION**

Usually swimmers breathe out from the nose while the face is in the water. We detected that nasal pressure adapted to water depth pressure automatically (Hara H., et al., 1998). To study effects on nasal pressure, the nostrils were covered with film while subjects did the breaststroke. In this case, of shutting down the nose, a person might not be able to feel pressure changes in that area (Hara H, et al., 2006). This disturbed the inhalation timing and resulted in swimming apnea. Experimentation in this form of nose-blocking has been carried out earlier (Hara H., et al., 2002).

In the present study, the airway changes from nose to mouth were defined, when four trained subjects were swimming simulated breaststroke. The nose pressure suddenly decreased when the nose broke the surface of the water. We think such a change of nasal pressure stopped exhalation from the nose. This also brings about a large blow-out from the mouth. The strong exhalation from the mouth needs a closing of the airways to the nose. Pronouncing “Mnn” facilitates exhaling from the nose, while pronouncing “Pa” or “Pha” will shut the nasal airways leading to exhalation from the mouth. Trained swimmers breathe out of the nose while their faces are in the water. In the case of instruction for beginners, to prevent swimming apnea it is effective if the instructor has the learner pronounce “Mnn” with the nose, then once that is completed, pronounce “Pha” or “Pa” from the mouth to blow out.

The ventilation volume from the nose is smaller than from the mouth. However, the flow volume sensor in the nose is more sensitive than that in the mouth (Thubone H. 1990). Moreover, because the diameter of the nasal airways is smaller than the mouth’s, flow volume and pressure might be useful for providing information for breath control. This is the reason for using the nasal passages while swimming (Wheatly, JR., et al., 1991).

In the case of sleep apnea, airway condition is very important for breathing (Amal MO, et al., 2004). Airway conditions are controlled by the autonomic nervous system. When attempting to pronounce a word, one controls the palate movement, intentionally. To prevent swimming apnea it is important for novice swimmers to acquire appropriate breathing skills in their swimming skill progression.

**CONCLUSION**

In conclusion, it was verified that trained swimmers vary the amount of air blown out of the nose and mouth, independently. In swimming, to protect from apnea, blow out from nose and stop breathing, then feel non water pressure in nostrils. After that, change the airway to the mouth for large volume exhalation. This process is developed through palate control. We find that to acquire this intentional airway control, word pronouncing is appropriate.

**REFERENCES**


**ACKNOWLEDGEMENTS**

The study was supported in part by Kokugakuin University, Specially Promoted Research, 2007. We acknowledge the students at Kokugakuin University and Kawasaki University of Medical Welfare for their participation in this study.
Performance Level Differences in Swimming:
Relative Contributions of Strength and Technique

Havriluk, R.

Swimming Technology Research, Tallahassee, USA

The purpose of this study was to compare the relative contributions of strength (measured by force, F) and technique (measured by the active drag coefficient, C_d) to swimming performance. Male (n = 40) and female (n = 40) swimmers were tested with Aquanex+Video swimming four trials (one of each stroke) over a 20 m course. Underwater video, hand force data, and swim time were collected over the last 10 m. The magnitude of the difference between faster and slower swimmers in both F and C_d was calculated as an effect size (ES). The mean ES for the C_d was almost double the ES for F, indicating that the advantage faster swimmers have over slower swimmers is derived more from technique than strength. Coaches can use this information to implement the most appropriate interventions for continued improvement.

Key words: strength, technique, hand force, active drag coefficient, biomechanics

INTRODUCTION

The drag equation explains swimming performance as: \( v \approx \sqrt{\frac{F}{C_d}} \), where \( v \) is swimming velocity, \( F \) is force, and \( C_d \) is the active drag coefficient. Consistent with this equation, previous research found that \( v \) increases with \( \sqrt{F} \) (Havriluk, 2004), and that faster swimmers have a lower \( C_d \) than slower swimmers (Havriluk, 2003). Other testing protocols (e.g. Takagi et al., 1983; Toussaint et al., 1988; White & Stager, 2004) also reported significant relationships of \( F \) and \( C_d \) with \( v \).

The importance of both strength (as measured by \( F \)) and technique (as measured by \( C_d \)) to swimming performance (as measured by \( v \)) is well established both theoretically and empirically. The relative contributions of \( F \) and \( C_d \) to performance, however, have not been determined. The purpose of this study was to determine how faster swimmers perform better than slower swimmers due to the relative contributions of strength (\( F \)) and technique (\( C_d \)), so that coaches can implement the most appropriate interventions for continued improvement.

METHOD

Swimmers from 21 teams volunteered to participate in the study. Male (n = 40) and female (n = 40) swimmers were tested with Aquanex+Video, swimming four trials (one of each stroke) over a 20 m course. The standard Aquanex testing protocol as described in previous research (e.g. Havriluk, 2003, 2004, 2006b) was used (see Figure 1).

Informed consent was obtained. Descriptive statistics for the male swimmers include: age in yrs (M = 18.0, SD = 1.3), height in cm (M = 180, SD = 7.7), mass in kg (M = 74.2, SD = 8.5) and for the females: age in yrs (M = 17.7, SD = 1.0), height in cm (M = 168, SD = 6.0), mass in kg (M = 62.1, SD = 6.5). Underwater video, hand force data, and swim time were collected over the last 10 m of each trial. The \( C_d \) was calculated as: \( C_d = \frac{F}{(\rho X v^2)} \), where \( F \) is the average normal hand force, \( \rho \) is the mass density of water, \( X \) is the cross-sectional area of the body, and \( v \) is swimming velocity. Previous research found an almost perfect correlation between normal and propulsive force (\( r = .98 \)) with a minor overestimation (6 N) of propulsive force (Havriluk, 2006b).
DISCUSSION

A previously conducted meta-analysis reported a wide range of values for the freestyle $C_d$ – from less than .5 to greater than 2.5 (Havriluk, 2007). $C_d$ values varied based on the testing protocol and associated sources of systematic error. As systematic error is so far unavoidable when measuring $C_d$, it is appropriate to identify known sources. The $C_d$ values for the present study were about 1.0 and have minor systematic error due to measurement of normal hand force as opposed to propulsive hand force (Havriluk, 2006b).

The significant curvilinear relationships of $v$ with $\sqrt{F}$ and $\sqrt{1/C_d}$ are consistent with the drag equation. The graphs in Figure 2 show the importance of both strength and technique to performance. These graphs also show proportionally smaller performance improvements with increases in $F$ and proportionally larger improvements with decreases in $C_d$, indicating that no matter how effective a swimmer’s technique, there is reason to continue to focus on improvement.

The performance level differences in $F$ and $C_d$ were expected, as was the gender difference in $F$ and the lack of a gender difference in $C_d$. The mean performance level ES for the $C_d$ was almost double the ES for $F$, indicating that the advantage faster swimmers have over slower swimmers is derived more from technique than strength. Slower swimmers can become more like faster swimmers by improving technique to reduce the magnitude of the effect. While the data show that faster swimmers have already benefitted from their technique, they can still improve. Because of the large gains in $v$ that result from small decreases in $C_d$, additional technique improvements are critical for even the fastest swimmers.

Since there is a smaller performance level difference in $F$ than $C_d$, faster swimmers may increase the difference in $F$ by increasing their strength. Because most competitive swimmers already strength train, however, additional gains may be difficult. A more productive approach may be to examine how swimmers apply their strength to the water as revealed by variations in hand force throughout the stroke cycle.

Hand force analysis identified wasted motion and force losses in even the fastest swimmers (Havriluk, 2006a). Recent research found that a group of college females wasted over 40% of the underwater butterfly arm motion with their arms in a mechanically disadvantageous position at the beginning of the pull (Becker & Havriluk, 2010). (Coincidentally, mechanically disadvantageous arm positions usually stress the shoulder in a manner that can cause injury.) Force losses of over 80 N have been measured on Olympians. These studies show that faster swimmers can benefit by minimizing wasted motion and force losses so that they use their strength more effectively.

Table 1. Mean (M) values for active drag coefficient ($C_d$), average hand force ($F$), and swimming velocity (SV) for faster and slower groups. Differences between groups are listed as effect sizes (ES).

<table>
<thead>
<tr>
<th></th>
<th>Males (n = 40)</th>
<th>Females (n = 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Faster</td>
<td>Slower</td>
</tr>
<tr>
<td>$C_d$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butterfly</td>
<td>0.89</td>
<td>1.16</td>
</tr>
<tr>
<td>Backstroke</td>
<td>1.10</td>
<td>1.35</td>
</tr>
<tr>
<td>Breaststroke</td>
<td>1.44</td>
<td>1.83</td>
</tr>
<tr>
<td>Freestyle</td>
<td>0.92</td>
<td>1.07</td>
</tr>
<tr>
<td>$F$ (N)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butterfly</td>
<td>85.9</td>
<td>81.4</td>
</tr>
<tr>
<td>Backstroke</td>
<td>77.5</td>
<td>65.7</td>
</tr>
<tr>
<td>Breaststroke</td>
<td>75.4</td>
<td>69.8</td>
</tr>
<tr>
<td>Freestyle</td>
<td>94.7</td>
<td>81.7</td>
</tr>
<tr>
<td>SV (m/sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butterfly</td>
<td>1.56</td>
<td>1.37</td>
</tr>
<tr>
<td>Backstroke</td>
<td>1.34</td>
<td>1.14</td>
</tr>
<tr>
<td>Breaststroke</td>
<td>1.16</td>
<td>1.00</td>
</tr>
<tr>
<td>Freestyle</td>
<td>1.62</td>
<td>1.44</td>
</tr>
</tbody>
</table>

Figure 3. Graph of the differences between faster and slower swimmers (expressed as effect sizes) in active drag coefficient and average hand force for 8 gender/stroke combinations. The diagonal line represents an equal effect from both variables.

Figure 2. Graphs of swimming velocity vs hand force and active drag coefficient.
Synchronized underwater video and hand force data shows swimmers and coaches exactly where in the stroke cycle that wasted motion and force losses occur. For example, the swimmer in the left image of Figure 4 shows .2 sec of wasted motion at the beginning of the butterfly pull and the swimmer in the right image shows a major force loss as the arms pass under the shoulders. Armed with this information, the coach can suggest technique adjustments to minimize these limiting factors. When a quantitative analysis is not feasible, coaches can qualitatively evaluate swimmers to identify wasted motion (as shown by excess lateral hand motion) and force losses (as shown by sudden changes in hand path). Coaches can then target control of the hand path angle to help a swimmer overcome these limitations. A quantitative analysis, however, is the most definitive way to identify limitations, confirm the effect of technique adjustments, provide numerical feedback to swimmers, and ensure that swimmers make the precise changes to optimize performance.

CONCLUSIONS

Coaches can help slower swimmers improve by emphasizing technique instruction and regularly measuring their $C^d$. Because of the large gains in $v$ that result from small decreases in $C^d$, even the fastest swimmers can continue to benefit from improving technique. Faster swimmers can also gain a greater advantage over slower swimmers from a more effective use of strength. With a detailed hand force analysis, a coach can identify wasted motion and force losses to provide options that increase average force and achieve maximum performance potential.

REFERENCES


Evaluation of Kinaesthetic Differentiation Abilities in Male and Female Swimmers

Invernizzi, P.L., Longo, S., Scurati, R., Michielon, G.
Università degli Studi di Milano, Facoltà di Scienze Motorie, Milan, Italy

Events longer than 50 meters require some tactical skills in order to manage the increase of fatigue, such as distributing the effort evenly over the whole distance. Kinaesthetic differentiation skills are required to achieve a very high precision of the movements. The repeatability of two procedures, aimed to measure the kinaesthetic differentiation abilities of swimmers was studied and the correlations between the actual performances and the expected performances with respect to gender and to the degree of change in velocity, were observed. Collecting the data in a single day and during four days running resulted in reliable results. Male swimmers seem to differentiate better than females and show a generally higher coefficient of correlation between the actual and the expected performance.

Key words: kinaesthetic differentiation, sensory perception, motor control

INTRODUCTION
Physiological factors such as strength and power, and technique and the ability to reduce drag, are the main factors determining swimming performance.

Furthermore, any event longer than 50 meters requires that swimmers employ some tactical skills, such as distributing effort evenly over the whole distance, in order to manage increasing fatigue. Even high-level athletes tend to swim too fast the first part of the event compromising the whole performance (Maglischo, 2003), especially during short distance events.

The control of swimming pace largely depends on coordinative and on sensory-perceptive abilities. The interaction between feedback and sensory-perceptive information allows full control of the movement. Furthermore, thanks to motor memory, the movement's regulatory system can precisely differentiate and manage the intensity of effort (Bernstein, 1975). Kinaesthetic differentiation abilities seem to have a progressive development with age, a plateau during puberty, an increase (Bernstein, 1975). Kinaesthetic differentiation abilities seem to have a progressive development with age, a plateau during puberty, an increase

Furthermore, any event longer than 50 meters requires that swimmers employ some tactical skills, such as distributing effort evenly over the whole distance, in order to manage increasing fatigue. Even high-level athletes tend to swim too fast the first part of the event compromising the whole performance (Maglischo, 2003), especially during short distance events.

The control of swimming pace largely depends on coordinative and on sensory-perceptive abilities. The interaction between feedback and sensory-perceptive information allows full control of the movement. Furthermore, thanks to motor memory, the movement's regulatory system can precisely differentiate and manage the intensity of effort (Bernstein, 1975). Kinaesthetic differentiation abilities seem to have a progressive development with age, a plateau during puberty, an increase (Bernstein, 1975). Kinaesthetic differentiation abilities seem to have a progressive development with age, a plateau during puberty, an increase

Kinaesthetic differentiation skills are thus important to perfect the swim. Thanks to these abilities, swimmers can achieve a very high precision of movement, having good control even when no visual feedback is allowed, bringing the execution of the movement closer to the ideal (Schicke, 1982), improving the “feeling of the water” and thus performing better propulsive actions or better reducing drag forces (Colwin, 2002).

This study aimed to verify the repeatability of measuring and evaluating the kinaesthetic differentiation abilities in good-level swimmers by two different procedures based on simply swimming at different speeds. The correlations between the actual performances and the expected performances were also observed with respect to gender and to the degree of change in speed.

METHODS
Eighteen swimmers aged 13 to 19 years, of regional to national level, participated in this study: 8 male swimmers (mean±SD, age 15.38±1.84 years, height 168.9±11.7 cm, weight 57.6±13.3 kg, BMI 20.0±2.4 kg·m⁻²) and 10 female swimmers (mean±SD, age 15.75±1.39 years, height 167.8±6.0 cm, weight 57.9±8.8 kg, BMI 20.5±2.8 kg·m⁻²).

To measure their kinaesthetic differentiation ability, the subjects performed a number of 25m front crawl trials at different paces corresponding to 50% and 80% of the maximum speed.

Each trial started without pushing-off the wall, the swimmer being supported in a streamlined, prone position. First, the swimmers performed a 25m front crawl trial at maximum speed (25m₁₀₀% max). The speed corresponding to 50% and 80% of maximum was immediately calculated by an MSExcel worksheet and communicated to the swimmer. Afterwards they were asked to perform a total of eight 25m swims as closely as possible to the requested speed (4 trials at 50% and 4 trials at 80% respectively).

The time of each 25m performance and the time for the central 10 meters (from 7.5m to 17.5m) were recorded.

Feedback was given after each trial: the swimmers were advised of their performance on a scale of 1 to 10, 10 corresponding to the 100% (maximum), 8 for the 80% effort, and 5 for the 50% effort. This was done in order to make the perception of speed easier for the younger swimmers.

Two different procedures were employed: i. Procedure 8/1, executing the protocol in a single day; ii. Procedure 8/4, executing the protocol over four days.

8/1: The swimmers performed 4 consecutive 25m front crawl trials at 50% of the maximum followed by 4 consecutive 25m front crawl trials at 80% of maximum on the same day. Full recovery was allowed between trials and feedback from the previous performance was given, as explained above.

8/4: The swimmers performed two trials per day, over four days. Each day, a 25m front crawl trial at 50% of maximum and after full recovery one at 80% of maximum, were performed. Feedback of the results from the previous day was provided before starting.

Statistical analysis was carried out using SPSS 13.0 software. The normal distribution of the data was verified by the Shapiro-Wilk test and parametric statistics were applied. Test validity was analyzed by the Intraclass Correlation Coefficient (ICC). Afterwards, by both gender and procedure (8/1 and 8/4), the Pearson's Correlation Coefficient between the actual and the expected performance was calculated.

RESULTS
The validity and the repeatability of the procedures employed in this study are shown in Table 1.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Intensity</th>
<th>r (10m)</th>
<th>r (25m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>50%</td>
<td>0.76*</td>
<td>0.84**</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>0.56</td>
<td>0.75*</td>
</tr>
<tr>
<td>Females</td>
<td>50%</td>
<td>0.74*</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>0.73*</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Table 1. Validity of the test (ICC)

The ability of the swimmers to perform 25m front crawl at a given speed corresponding to 50% and 80% of their maximum is illustrated in Tables 2 and 3: correlations with the 25m₁₀₀% front crawl trials are shown. Both procedures (all trials in a single day and two trials in four days running) have been considered.

Table 2. Correlation (Pearson's) by gender in the 8/1 procedure between the performance and the expected speed at 50%max and 80%max. Values refer to the whole distance (25m) and to 7.5m to 17.5m (10m). * = p<0.05; ** = p<0.01.
Table 3. Correlation (Pearson’s r) by gender in the 8/4 procedure between the performance and the expected speed at 50%max and 80%max. Values refer to the whole distance (25m) and to 7.5m to 17.5m (10m).

<table>
<thead>
<tr>
<th>Gender</th>
<th>Intensity</th>
<th>r (10m)</th>
<th>r (25m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>50%</td>
<td>0.68</td>
<td>0.72*</td>
</tr>
<tr>
<td>Females</td>
<td>50%</td>
<td>0.44</td>
<td>0.61</td>
</tr>
<tr>
<td>Males</td>
<td>80%</td>
<td>0.50</td>
<td>0.73*</td>
</tr>
<tr>
<td>Females</td>
<td>80%</td>
<td>0.51</td>
<td>0.77*</td>
</tr>
</tbody>
</table>

**DISCUSSION**

The reliability of the procedures has been verified. The 0.77 ICC value denotes that the performances of the swimmers, indicating their kinaesthetic differentiation abilities, can be measured reliably. It is therefore possible to measure the adaptation strategies aimed at managing the speed of the swim, thus the expressions of strength, power and the actions required to deal with the swim.

In male swimmers, there is little difference between the two procedures (8/1 and 8/4). Males are very able to adapt their speed during the 25m trials to the requested pace, both in procedure 8/1 and 8/4. The immediate feedback in the 8/1 procedure, simpler than the other one, certainly had an effect on swimming at the requested speed, but similar correlations were also found in the 8/4 procedure (R = 0.84 and 0.75 in the 50%max and 80%max of the 8/1 procedure, respectively; R = 0.72 and 0.73 in the 50%max and 80%max of the 8/4 procedure, respectively). Regardless of whether 50%max or 80%max speed is requested, the performances of the male subjects showed high correlations to the expected swims.

At 80%max, the central 10m did not correlate well with the expected speed. Males seem to correctly perform only at 50%max (R = 0.76 and 0.68 in the 8/1 and 8/4 procedure respectively). This may be due to the fact that at 80%max male swimmers can manage the timing mainly on the 25m not in the central 10m. In fact, the 25m performance involves the starting dive and swimmers are well used to train on this distance to improve their stroke frequency. Therefore the 10m average speed, collected just after the starting dive, might not be representative of the average speed of the whole performance. This point highlights that at high speed, such as 80%max, it appears that males tend not to be constant in the speed distribution on the 25m, a fact that seems to occur at lower speed, e.g. 50%max.

Female swimmers seem to have more difficulty than males in adapting the swim to the targeted speed. In the 25m an acceptable correlation was found only in the 8/4 procedure (R = 0.61 and 0.77 in the 50%max and 80%max, respectively). The subjects recorded a poor correlation in the 8/1 procedure, despite the presence of immediate feedback (R = 0.54 and 0.57 in the 50%max and 80%max, respectively). Looking at the central 10m a good correlation in the 8/1 procedure (R = 0.74 and 0.73 in the 50%max and 80%max, respectively) and a non significant correlation in the 8/4 procedure (R = 0.44 and 0.50 in the 50%max and 80%max, respectively) were found. In this case it seems that females had more difficulty dealing with the distribution of effort, confirming the literature that shows a lower degree of the differentiation abilities in females than males (Hirtz, 1988).

Finally, the females reproduced the stipulated speed better at 80%max than at 50%max, whereas the male subjects demonstrated the opposite. This is in partial discordance to previous findings in master athletes (Invernizzi et al., 2005) where the management of the performances at 80% of the maximum resulted better than at 50% of the maximum both in male and in female subjects. In that protocol, diving was not executed and subjects were asked to perform the trial starting in the water. Hence a different way in organizing the distribution of the effort could have been employed by the male swimmers, often practicing during training sessions the 25m short distance, as explained before. Moreover young male swimmers seem to swim faster than requested at 80%max compared to 50%max. This could be related to an observable competitive temper, higher in males than in females.

**CONCLUSION**

The measurement of performance related to the kinaesthetic differentiation abilities is reliable. Both the single day and the four-day protocol can be employed.

Male swimmers seem to differentiate better and show a generally higher coefficient of correlation between the actual and the expected performance than the female subjects.

Interesting practical applications for coaches and athletes could originate from this methodology to evaluate and to train kinaesthetic differentiation ability in order to better manage swimming pace.

**REFERENCES**

Swimming in Eyesight Deprivation: Relationships with Sensory-Perception, Coordination and Laterality

Invernizzi, P.L., Longo, S., Tadini, F., Scurati, R.

Università degli Studi di Milano, Facoltà di Scienze Motorie, Milan, Italy

Maintaining control of direction during displacement is important in swimming, particularly for backstroke and open water events. Sensory-perception, coordination and laterality can relate to the ability to swim straight. This study aimed to analyze these relationships in front crawl, backstroke and breaststroke swum in a condition of eyesight deprivation. High correlation was found between the sensory-perception abilities and the ability in blind straight swimming. A crossed dominance seems to be related to a better ability to manage the swimming direction in breaststroke, but neither in front crawl nor in backstroke.

Keywords: sensory-perception, coordination, gliding

INTRODUCTION

Previous studies on technical and coordinative skills and on sensory-perception abilities pointed out the importance of kinaesthetic differentiation skills and of the ability to reduce the drag forces in swimming performance.

We wondered about the role of kinaesthetic differentiation and coordination in keeping control of the swim direction, managing straight swimming. Usually athletes do not focus on it, thanks to the unconscious collection of information through eyesight (e.g. the lane line, the lane ropes, the walls). Swimmers should have good sensory-perception and kinaesthetic differentiation skills because these abilities allow them to perform the propulsive actions having good control even with no visual feedback. Moreover they would be able to execute optimal swimming close to a theoretical model (Schicke, 1982). This is important in order to best manage the swimming direction, particularly in events such as backstroke or open water.

The sensory-perception abilities are also essential to build “feeling for the water” and they can be improved anytime by practice (Colwin, 2002). Furthermore they are closely related to coordination (Meinel et al., 1984) and to balance, both during swimming and outside the water. Visual feedback is closely related to balance, to sensory-perception improvement and to the control of direction during displacement (Danion et al., 2000). Relationships are also found between coordination and laterality (hand dominance) (Oberbeck, 1989).

The evaluation of coordination can be accomplished through a test based on the measurement of the maximal rotation on the longitudinal axis the athlete performs (Starosta, 2004). The laterality of subjects (hand dominance) could be calculated through the Hildreth index (Cilia et al., 1996), from the frequency of the favourite side used while performing a number of simple tasks.

The ability to reduce drag, connected to swimming specific sensory-perception abilities, can be evaluated by a gliding or a dive and glide test (Cazorla, 1993; Invernizzi et al., 2007).

The aim of this study was to analyze the relationships among sensory-perception abilities, eyesight, coordination and laterality in maintaining a straight swim during the front crawl, the backstroke and the breaststroke, in young swimmers aged 8 to 14 years.

METHODS

Twenty-eight young swimmers participated in this study (mean±SD, age 10.8±1.3 years, height 146.2±11.3 cm, weight 37.7±8.8 kg, BMI 16.9±2.2 kg/m², arm span 148.7±13.5 cm).

To evaluate the trajectory of the swim without the support of visual feedback, the swimmers were asked to swim wearing dark goggles (Novák, 1982). A total of 9 blind-trials were performed: strokes were repeated three times in the sequence 25m front crawl, 25m backstroke and 25m breaststroke to avoid any conditioning effect due to the protocol.

Subjects swam in the middle of a double lane area, starting in a prone or supine position, pushing off the wall with both legs. They were asked to perform the swim as straight as possible, feeling the water displacement only through kinaesthetic and vestibular sensory perception feedback.

Scores (-5 to 5) were assigned depending on where the swimmers touched the lane rope or the end wall (Figure 1). Assistants guaranteed the safety of the subjects and the survey was supported by video-recording.

Positive scores indicated a deviation to the left whereas negative scores indicated a deviation to the right. The scores have been inverted for backstroke in order to have the same meaning of the direction of deviation with respect to the swimmer’s body.

Swimmers performed the front crawl stroke breathing every three armstrokes (alternating the side of breathing).

Figure 1. Experimental setting for the “blind swimming” evaluation.

The swimmers’ coordination was evaluated through a Coordination test as suggested by Starosta (2004). Subjects had to jump on a 1 square meter base (Figure 2), executing the maximal possible rotation on the longitudinal axis during the flight. Athletes could make free use of upper limbs. The degree of rotation was collected from the position of the feet after landing. Two trials were performed for each direction of rotation.

The preferred direction to rotate was also detected from the results.
Figure 2. Experimental setting for the evaluation of the coordination.

The Hildreth index (Cilia et al., 1996) was employed in order to evaluate the laterality of the subjects (hand dominance). According to the protocol, twelve actions for each part (e.g. hand, foot, eye) are selected and the preferred side employed during the test is recorded. The index was calculated as follows: (nr of trials executed on the right – nr of trials executed on the left) / 12. Based on the results (-100 to 100) it is possible to define the side and the degree of the laterality. In our study the twelve actions using the hands were selected and the frequency of employment in the action requested was surveyed.

The ability to "feel the water" strictly depends on sensory-perceptive skills, hence the "dive and glide" test was applied to evaluate it (Cazorla, 1993; Invernizzi et al., 2007). The distance reached by the swimmers after gliding was measured. Neither movements nor propulsive actions were allowed during the gliding phase.

The relationships observed were: blind swimming and swimming style, blind swimming and coordination, blind swimming and gliding. Results were also discussed with respect to the swimmers laterality.

Statistical analyses were carried out by SPSS 13.0® software, using \( p<0.05 \). The normal distribution of the data was verified by the Shapiro-Wilk test.

Correlations were verified by Pearson’s correlation coefficient. A paired Student’s t test was applied where appropriate.

RESULTS

The relationships of the deviations among styles in blind swimming, are shown in Figure 3. Figure 4 shows the relationship between blind swimming deviation and coordination evaluated by Starosta’s test. In Figure 5, deviations in blind swimming have been related to dive and glide and gliding only.

Figure 3 – Correlations between each style and the deviation (sum of the absolute score values) in blind swimming.
No relationship was found between the degree of coordination and the amount of deviation in blind swimming (Figure 4). Probably Starosta's test cannot be used alone to represent swimming coordination. Starosta's test showed, in accordance to the literature, that most RH-LL dominant athletes (about 70%) prefer turning counter clock-wise (Oberbeck, 1989).

Both the dive and glide and the gliding test alone, are closely related to the ability to perform straight blind swimming (Figure 5, p<0.01). The gliding test is a reliable method to evaluate sensory-perception abilities (Invernizzi et al., 2007; Cazorla, 1993), and it supports the relationship between correct discrimination in managing feedback and body posture or movement.

The significant difference found in the blind breaststroke between RH-LL and RH-RL supports the hypothesis that RH-LL better manage the direction of swimming than RH-RL. The literature shows that RH-LL subjects show a higher level of performance than subjects with other forms of laterality, such as RH-RL or left hand dominance (Oberbeck, 1989). The symmetric movements of upper limbs are easier to learn and to manage than the asymmetric ones (Farfel, 1988). Hence RH-LL athletes compared to RH-RL could better perform a straight swim only in breaststroke, not in front crawl and backstroke, because the motor control of these strokes seems to be more difficult.

CONCLUSION
This study confirmed the importance of evaluating sensory-perception abilities, coordination and hand and leg dominance in swimming.

Further studies should aim to relate them also to conditional characteristics such as strength and power.

Guide lines for transferring the findings into practice suggest that the enhancement of the sensory-perception system could improve swimming skills and the management of the feedback. Breaststroke could be used to practice balance during propulsive actions, better dealing with control of the direction of swim displacement.

REFERENCES


Progression in Teaching Beginning Swimming: Rank Order by Degree of Difficulty

Junge, M. 1,3 , Blixt, T. 2 , Stallman, R.K. 1,2

1Norwegian School of Sport Science, 2 Norwegian Swimming Federation, 3University of Oslo

"Teach first things first": But what comes first? Where do we start? Also, children are different and no progression will suit all. It should be possible to a) agree on content and b) find a progression that suits a majority. Children 5-6 yrs of age (N=146) received 18 hrs of instruction, in small groups. A theoretical progression of 19 skills was created from the international literature, examining course content of leading educational organizations. A single head instructor coordinated all teaching. Evaluation of progress and recording of criterion success on the 19 skills was overseen by the same head instructor. The number of children succeeding on each skill was deemed a reflection of the degree of difficulty. The actual rank order of skills derived from these learners was correlated to the theoretical rank order using Spearman's rank order correlation. Rho proved to be 0.97. Among other results, all (paired) skills on the front proved easier than the corresponding skill on the back. Arguments are presented to defend retaining the theoretical rank order as well as arguments for adjusting the rank order. When individualising teaching, there seems to be an optimal progression for each child, albeit slightly different from one child to another. It was surmised that degree of difficulty may not be the only criterion to be used when creating a progression.

Key words: learn to swim, progression, rank order, degree of difficulty

INTRODUCTION
There remains disagreement among experts and organizations as to both content and ranking of skills by degree of difficulty in teaching beginning swimming. If one attempts to “teach first things first” several factors must be considered. Before organizing skills according to degree of difficulty, what skills to include must first be considered. As stated above, there is as of 2010, no broad agreement. Traditionally however, such general statements as the following have been broadly accepted:

“Swimming, in contrast to other physical activities has a clear survival value” (Junge, 1984)
“Learning to swim should be part of every persons general education” (Langendorfer & Bruya, 1995)
“The teaching of swimming should produce independence/self dependence in the water”
“The aim of swimming lessons is to help to prevent drowning”
“The ability to swim is reflected in how far one can move the body through the water”
“Breath control is the key to water safety” (American Red Cross, 1951; Lane, 1963)
“A person who can swim is one who can cope with an unexpected submersion in the water” (Whiting, 1971)

We could go on with such statements; there are many. They may indeed be necessary as aims for organized teaching and would be difficult to disagree with. They have become platitudes and will not take us to the next step.

There does appear to be a trend among researchers and educational organizations linking content in learn to swim with the causes of drowning (Stallman, et al, 2008). The issue remains complex because of the discussion (among others) of the use of flotation devices. Inherent in this discussion is the philosophy one uses, i.e. how does one define swimming, how does one think of swimming. Those who perceive swimming to be the use of the arms and legs to propel oneself forward may believe that the use of flotation devices allows earlier attention to the learning of propelling movements. Those who believe swimming to be much more than only propulsion are normally in no hurry to start these “correct swimming movements”. There is increased agreement on breath control, buoyancy control, gliding and postural control and stroking skills. Also, all around development (watermanship) has enjoyed a revitalization with the concepts of “aquatic readiness” and “water competence”. (Langendorfer & Bruya, 1995).

The aims of this study were a) to create a theoretical progression of skills by implied degree of difficulty and b) to evaluate the rank order of these skills against the actual rank order as demonstrated by the achievement of selected learners.

METHODS
A progression of 19 skills was created by synthesizing the progressions of several well established national organizations, according to implied degree of difficulty. These skills were categorized as follows:

a. Breath holding, breathing, breath control and submersion
b. Floating, buoyancy control, postural control
c. Gliding, posture and position control, feeling motion and resistance
d. Propulsive skills, feeling grip (resistance on propulsive surfaces)

Included in each of these categories, often as supplementary or intermediate goals and teaching exercises, were skills of orientation, balance and rotation.

Pre-school children, aged 5 & 6 years were selected from 13 kindergartens. Inclusion criteria were a) minimum height 1.15m, b) previous experience in kindergarten, c) could not swim 5m. Of the 146 children who started the program, 116 met the 4th criterion of a minimum of 50% participation and were included in the analysis for degree of difficulty.

The instructional period consisted of 18 hrs., some groups meeting once per week, others twice per week. The data for these two groups were pooled when subsequent analysis showed no difference in learning progress. Instruction was given in small groups with 6-8 children and no more than 3 groups in the pool simultaneously. A single head instructor controlled all teaching and especially the recording of successful completion of each test criterion skill.

The actual rank order of skills by degree of difficulty as shown by these learners progress was deemed reflected in the number of children who succeeded on each skill. The theoretical rank order of skills was compared to the actual rank order using Spearman’s rank order correlation.

RESULTS
Table 1 shows the theoretical rank order of skills in column one. Column 2 shows the actual rank order as reflected in the total number of children (in parentheses) who mastered each skill. The rank correlation between these two progressions was Rho = 0.97, indicating a very strong relationship. While the difference appears to be minimal, there were in fact 7 of the 19 skills which differ in rank order indicating a very strong relationship. While the difference appears to be minimal, there were in fact 7 of the 19 skills which differ in rank order.

The first example of deviation is found already in steps 1-3 where submerging the head and holding the breath for 10 sec. seems to be more difficult than both rhythmic breathing and jump and submerge. The next notable deviation was that it appears that front glide was easier and front kick glide was at least as easy as float on the back. Rolling from front to back and vice versa was more difficult than both front glide and back glide.
and back (10m). and was virtually non existent by 15 & 16, beginning swim on the front prone position diminished in the following paired skills systematically named paired skills, the most dramatic was that 84% learned to float than the same skill on the back.

<table>
<thead>
<tr>
<th>Progressive Skills &amp; Criterion</th>
<th>Theoretical rank order</th>
<th>Actual Order (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Head under water, 10 sec</td>
<td>3 (97)</td>
<td></td>
</tr>
<tr>
<td>2. Rhythmic breathing, 10 reps</td>
<td>1.5 (102)</td>
<td></td>
</tr>
<tr>
<td>3. Jump to head under water</td>
<td>1.5 (102)</td>
<td></td>
</tr>
<tr>
<td>4. Float on front, 15 sec</td>
<td>4 (90)</td>
<td></td>
</tr>
<tr>
<td>5. Float on back, 15 sec</td>
<td>6.5 (64)</td>
<td></td>
</tr>
<tr>
<td>6. Roll front to back and vice versa</td>
<td>9 (60)</td>
<td></td>
</tr>
<tr>
<td>7. Front glide, 5 m</td>
<td>5 (79)</td>
<td></td>
</tr>
<tr>
<td>8. Back glide, 5 m</td>
<td>8 (61)</td>
<td></td>
</tr>
<tr>
<td>9. Kick glide (front or back), 5 m</td>
<td>6.5 (64)</td>
<td></td>
</tr>
<tr>
<td>10. Front kick glide, 10 m</td>
<td>10 (50)</td>
<td></td>
</tr>
<tr>
<td>11. Back kick glide,10 m</td>
<td>12 (34)</td>
<td></td>
</tr>
<tr>
<td>12. Jump and float up (front &amp; back)</td>
<td>11 (36)</td>
<td></td>
</tr>
<tr>
<td>13. Beginning armstroke on front10 m</td>
<td>13 (29)</td>
<td></td>
</tr>
<tr>
<td>14. Beginning armstroke on back10 m</td>
<td>14.5 (26)</td>
<td></td>
</tr>
<tr>
<td>15. Beginning swim on front with rhythmic breathing10m</td>
<td>14.5 (26)</td>
<td></td>
</tr>
<tr>
<td>16. Beginning swim on back with rhythmic breathing10 m</td>
<td>16 (24)</td>
<td></td>
</tr>
<tr>
<td>17. Change direction, L &amp; R, Front &amp; Back</td>
<td>17 (23)</td>
<td></td>
</tr>
<tr>
<td>18. Rest in deep water (Fr &amp; bk, minimal movement. 30 sec</td>
<td>18.5 (17)</td>
<td></td>
</tr>
<tr>
<td>19. Combined test (Jump, 12.5 fr; rest 30 sec; turn, 12.5 back)</td>
<td>18.5 (17)</td>
<td></td>
</tr>
</tbody>
</table>

In every case where the skills are paired front and back (Nrs. 4 & 5, 7 & 8, 10 & 11, 13 & 14, 15 & 16) executing the skill on the front was easier than the same skill on the back.

Lastly, when considering the proportional success on the above named paired skills, the most dramatic was that 84% learned to float on the front first and later on the back. The apparent relative ease of the prone position diminished in the following paired skills systematically and was virtually non existent by 15 & 16, beginning swim on the front and back (10m).

**DISCUSSION**

The Rho of 0.97 suggests that there may be no statistical need to alter the theoretical rank order. Such a high Rho must however, be taken cautiously. One of the variables was fixed in ascending order. Other confounding factors may have influenced the results. The deviations described also invite discussion regarding possible adjustments for pedagogical reasons. Extremely interesting arguments for and against can be made. There may be several factors which should be debated in this instance.

First and most important, children are so different that no progression will suit all. Using the example of floating, the theoretical rank order proved to be correct for 84% of the children tested. It was not correct for the remaining 16%. For these children it was entirely normal to learn to float on the back first. For them, the rank order was in fact, adjusted by these children themselves. They showed the way. Thus, while less frequent, this development is by no means abnormal. The consequence of this situation is simply that the instructor would be well advised to start with front float but immediately when some have difficulty, suspect that they may belong to the 16% and give back float a try.

The second factor is the concept of building blocks or aquatic readiness (Langendorfer & Bruya, 1995). Here the first 3 skills and their relationship to both 4 & 5, as well as the remaining paired skills may best exemplify this concept. Item 1 appeared to be more difficult than both 2 and 3. It may be that the difficulty lies not in the relaxed submerging but in the 10 sec. criterion. If breath holding for 10 sec or even longer may in some ways be a prerequisite for what comes later, perhaps one needs simply to spend more time on this item until it is more thoroughly mastered, before proceeding. It is entirely possible that both rhythmic breathing and jump and submerge would have reached a higher level had more time been spent on breath holding. Also to master floating on the front for 15 sec. one has a good start if making sure that 10 sec. along the way is easily manageable. Note that several of the following paired skills are also dependent on breath holding/breath control. We might also speculate that the apparent difficulty with back float was in some way connected with the level of competence attained on the first four items. When the instructor is faced with a learner who struggles a bit with front or back float, it may not be the relationship between these two that is the problem but insufficient mastery of the first three skills. The same could be said for rolling from front to back and vice versa (nr. 6). Finally, when both front and back glide were easier than rolling over, it can be assumed that training on the glide also improved those factors upon which rolling depends. The question then is simply, should one dwell a bit longer on front and back float, present them in greater variety or delay rolling from front to back until after gliding has been mastered?

The third factor which presents the opportunity for reflection is the concept of balanced progress. Skills are normally acquired in an overlapping fashion. It is recommended to work on several skills at a time. This also allows greater flexibility for the learners to find their own way, their own correct progression. If one were to strictly follow the rank order as shown by the subjects in this study, one would move from front float to front glide and to front kick glide, all of which appeared to be easier than back float. An argument in favor of this might be that they are sufficiently related that they invite transfer of learning and that this order would be easily understood by learners. If one followed such a course, one would then do the same on the back. A counter argument might be that if one could stop the clock in a learners progress, one might ask “at this point in time, what combination of skills would make our learner most safe?” One answer might be that having some similar degree of proficiency on both back and front, at any given time, has a specific survival value.

**CONCLUSIONS**

It is possible to find the optimal progression for any learner. Since learners differ considerably, the instructor must be prepared for individualization. This is most easily done if the learners themselves are involved in certain decision making. When working on several related skills or skills of similar difficulty at the same time, the child will show the way. It is also well known that participation is greater when the child is involved in deciding. It is not a burden to cater to such individualization. It may in fact, make our job easier, by increasing motivation and by helping each individual child find their own optimal progression. Finally, other factors than simply degree of difficulty may be important in constructing a progression.

**REFERENCES**


The Construct Validity of a Traditional 25m Test of Swimming Competence

Junge, M.1,3, Blixt, T.2, Stallman, R.K.1,4

1Norwegian School of Sport Science, 2Norwegian Swimming Federation, 3University of Oslo, 4Norwegian Life Saving Association

A universal definition of the ability to swim has yet to be agreed upon. Some believe that “how far” one swims is the most important criterion. The number of meters is controversial. Some use a traditional definition of from 25m to 200m, often as the only criterion of “can swim”. In fact, this is not the point. A conceptual model emphasizes broader competence. The result of this model is a combined test including more than only distance. This combined test was used as the criterion to test the construct validity of a traditional test. When these two tests were compared they were found to be very different, thus measuring different qualities. Among children already declared able to swim by the traditional test, only 5.7% satisfied the conditions of the conceptual test. It was concluded that the traditional test was not a valid measure of the ability to swim.

Key words: evaluation, swimming competence, validity, distance test

INTRODUCTION
Learn to swim programs remain dramatically different in their content and in the manner in which the learner's progress is evaluated, in other words, by which criteria a child is judged "able to swim". There is fortunately, growing agreement among researchers and educators on the importance of a) breath holding, breath control, b) floating, buoyancy control, c) gliding and postural control, and d) stroking and directional control, as well as orientation, balance and rotation (Stallman, et al, 2008). These are seen as essential, core elements. There remain however, many ideas about how and what a child should learn. The less experienced person (school teacher who is not a swimming instructor, parent, significant other) is more prone to fall prey to misconceptions. In a recent Scandinavian questionnaire investigation, it was revealed that almost every primary school head master had her/his own definition (Directory of Education, Norway, 2008).

There also remains a traditional notion that the number of meters achieved is the only or most important criterion for defining the ability to swim. This is especially true among parents but sadly, remains common also among certain swimming instructors. A common complaint is that “we don’t have enough time”. The result is often a single selected stroke and a pre-determined distance (Directory of Education, Norway, 2008). The notion that some form of all around development is more important than simply a certain number of meters seems to have escaped closer scrutiny. A number of well known and respected national agencies (e.g. The American Red Cross, The German Life Saving Association, etc.) have long emphasized all-around development as essential in drowning prevention. The concepts of “watermanship” or “aquatic competence” are well known (Sinclair & Henry, 1893, Langendorfer & Bruya 1995). Both Cureton (1943) and the USA Navy (1943), emphasized that drowning can take many forms, and that these are unpredictable. Therefore, many solutions (all-around development) are necessary to solve many possible life threatening situations.

When considering the ultimate negative outcome of an aquatic “episode” (death by drowning) it is clear that a variety of skills is required to cope with the wide variety of possible situations in which an unsuspecting person might find themselves – in the water. It surely is obvious then that, one stroke or one distance is not sufficient. Unfortunately, some still appear to believe it is. And the discussion goes on, 25m, 100m, 200m? And of course, whatever conclusions one reaches about skills, we also tend to neglect knowledge, attitude and judgment.

The motive for this study was thus to examine the idea that it is not how far but how one swims that really matters. The aim of this study is thus, to examine the construct validity of a 25m test of swimming competence by comparing it with a criterion combined test, maintaining the same overall distance on both. It was also assumed that the same results would appear if a different distance had been chosen. For example, that a traditional test of 200m with single stroke is not the same as a 200m combined test with the same pattern as the shorter combined test.

METHOD
From among 200 primary school children, age 9&10 years, taught in a single school term, 70 succeeded in the local traditional test of negotiating 25m with no other criteria. These 70 were declared “able to swim”, awarded a pin and the parents were notified that their child could swim. These children (N=70) constituted the subjects of this study. By performing a second test, within 3 days of the first, they served as their own controls.

The criterion “combined test” consisted of: a) jump or dive into deep water (3m), level off, b) swim 12.5 m in the prone position c) turn 180 degrees, d) roll over e) rest for 30 sec with minimal movement, f) swim back to the starting point in the supine position. Diving was awarded two points, jump one point and 0 for those who refused both jump and dive. Each of the other elements was awarded two points. The maximum possible score was thus 12 points. The total distance was the same for both tests but the criterion test was obviously more comprehensive, included a more balanced skill profile.

The children were motivated by being offered a second, new award. No mention was made of the second test being a test of swimming ability nor was it implied that the first test was anything other than what they had believed it to be. To any direct question, the second test was simply referred to as a “new” test, and new award; swim or swim better.

The children were tested by their own teacher to avoid bias by altering the atmosphere. The observers who evaluated the performance were known to the children. The children were tested four at a time and each of two observers was assigned to two children. The same observers evaluated all of the subjects. Pilot testing was conducted to train the observers. Discussions were held to ensure that both observers used the same criteria. A head instructor coordinated all evaluation and made the final decision in any case not obvious in its outcome. Each element was scored and the total score was recorded. The results were tabulated by frequency distribution and both the number and percent of subjects succeeding on each element was recorded. The total scores were also recorded.

The criterion test was the result of a construct, i.e. a conceptual construction based on the logical arguments cited above. If these two tests gave similar results, the traditional test would be accepted as having construct validity. If the two tests differed they would be considered to measure different qualities and the traditional test would be considered not to have construct validity.

RESULTS
Table 1 shows the results by element. The results clearly show that all but the one element reproduced also on the first test, were not mastered by many of the children.

Table 1 Success by element on the combined criterion test

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Number (n = 70)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dive</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>Jump</td>
<td>36</td>
<td>51</td>
</tr>
<tr>
<td>Start in water</td>
<td>18</td>
<td>26</td>
</tr>
<tr>
<td>2. Swim 12.5m prone</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>3. Change direction 180°</td>
<td>63</td>
<td>90</td>
</tr>
<tr>
<td>4. Roll over</td>
<td>40</td>
<td>57</td>
</tr>
<tr>
<td>5. Stop &amp; rest 30 sec.</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>6. Swim 12.5m supine</td>
<td>36</td>
<td>51</td>
</tr>
</tbody>
</table>
As would be expected, 100% of the children who had already swum 25m on the front, succeeded in swimming 12.5m on the front. However from that point on, fewer managed the other elements. Twenty six percent refused to either jump or dive into deep water, asking to start in the water. Ten percent did not manage to change direction. Forty three percent were unable to roll over. Forty nine percent were unable to swim on the back. And lowest of all, only 5.7% managed to stop and rest, even for only 30 seconds.

The range of total scores was from 4 to 12. Only four of these pupils scored 11 or 12 points, i.e. by the criterion test, could swim.

**DISCUSSION**

The real issues here are, how do we evaluate whether a child can swim or not, and can a simple distance test serve the need to evaluate. To return to the idea that it is how one swims rather than how far, we must forsake traditional ideas of any given distance. Some insist on 25m, some on 200m, others are somewhere in between. It can be remembered that the Scouting movement has long operated with a 200yd (ca 180m) minimum before permitting boating activities (Scout Handbook, 1956).

Several national life saving organizations also have a tradition of focusing on 200m or 200 yds. In some cases, no other criteria are used. Can it be that one who can swim 200m but not 210m, can swim? How safe is this person? How are they prepared for the many possible scenarios one might be victim to in an involuntary submersion?

The results of this study show clearly that the two tests considered, measure different qualities. Being able to swim 25m non-stop on the front does not automatically give one the ability to swim in the back, turn, roll over, stop and rest or jump or dive into the water. (if an emergency required one to swim on the back or to stop and rest (gather ones wits, catch the breath, etc. It remains a mystery to us that the ability to stop and rest is as safe as they might have been if they had mastered the criterion test. Consider the statistic cited by Golden and Tipton (2002), that > 40% of drownings in the UK happen within 3m of safety. The logically matching scenario would require the victim to turn around and make their way back to safety. Cold shock also first described clearly by these same authors, operating outdoors, in colder and restless, open water, and perhaps fully clothed. But at what ever distance one arrests the learner’s progress, in a laboratory slice of life to be examined under the microscope, the pattern of versatility should be retained. Each element would then be increased to a higher level of challenge.

**CONCLUSIONS**

The distance test of 25m, with no other criteria, measures different qualities than the slightly more comprehensive combined criterion test. If we accept the construct validity of the criterion test, the traditional test is necessarily judged not to have construct validity.

**REFERENCES**


Higgins J., et al. (1943). Swimming and Diving. The United States Navy. United States naval Institute, Annapolis, MD


Using a Scalogram to Identify an Appropriate Instructional Order for Swimming Items

Langendorfer, S.J.¹, Chaya, J.A.²

¹Bowling Green State University
²University of Toledo

Scalogram, first proposed by Guttman (1950), is a descriptive ordering technique used in the social sciences to investigate how heterogeneous behavioral items may relate to one another in time. In the present study, we explored whether there was a predictable order of acquisition among selected swim skill items used in the instruction of swimming. If so, we might identify a preferred order in which to teach these swim skills. A convenience sample of thirty-one college students enrolled in University instructional swimming classes performed each of the items in random order while investigators videotaped each performance. After establishing inter-observer objectivity exceeding $P > 0.80$, the investigators observed each video trial and scored each item for each participant as pass-fail using pre-established criteria based on the American Red Cross Swimming and Water Safety learn-to-swim program (Red Cross, 2004). The Red Cross order for teaching the tested skills was confirmed as the best order identified by the scalogram for young adult participants with a coefficient of reproducibility of $CR = 0.93$. Limitations in the procedures and results suggested the need for several future studies to identify whether the order applied to other ages and ability levels as well as how susceptible the scalogram technique is to varying instructional experiences of participants.

Keywords: swim instruction, swimming skills, scalogram, developmental sequences

INTRODUCTION

The order in which different human behaviors are acquired has a long history of scholarly interest. Charles Darwin, in his “Biography of a Baby,” chronicled the behaviors and ages he observed his son acquire typical “motor milestones” (Darwin, 1877). Jean Piaget, the noted developmental psychologist and epistemologist, provided detailed descriptions of the order in which his own three children acquired various psychomotor, cognitive, and social behaviors during childhood (Piaget, 1973). During the heyday of infant motor development, developmental researchers such as Arnold Gesell (1940), Mary Shirley (1931), and Myrtle McGraw (1939; 1963; 1975) all proposed different sequences of infant behaviors. McGraw, specifically, focused on the description and order in which infant swimming behavior changes progressively over time (McGraw, 1939).

The order with which individuals acquire different skills has implications and importance to different clinicians and practitioners such as teachers and coaches. The logic is that easier tasks should be introduced or taught first. The basis for the developmental task analysis (Herkowitz, 1978; Roberton, 1989) or constraints-based task analysis approach (Haywood & Getchell, 2009) uses a similar logic for structuring motor skills. Developmental task analysis separates motor task factors and then organizes them according to the levels of complexity. In the developmental task analysis scheme, inexperienced performers encounter the least complex movement task factors first and then progressively experience more complicated levels to improve the success of movers. Presumably the acquisition of easier tasks serves to build foundational competence in learners as well as enhance their sense of self-confidence and success.

Guttman (1950) proposed an interesting technique called the scalogram for examining the robustness of order of acquisition for series of different behaviors. He proposed to discern item difficulty by examining a heterogeneous sample of individuals who attempted a series of items which were measured on a pass-fail (or dichotomous) basis. The reasoning behind the validity of the scalogram technique is that the easiest or least difficult items should be mastered by the most individuals because they are acquired first. As item difficulty increases, fewer and fewer individuals should be able to master the task. Consequently, the most difficult and presumably the last items in a series to be mastered will be able to be demonstrated by the fewest individuals. Using a matrix-like table, Guttman (1950) proposed a “coefficient of reproducibility” which repre- sents the average ratio between the total successful responses (or passed items) and the total possible number of responses (or product of items times participants). Like similar association coefficients, the coefficient can range from 0.0 to 1.0. A higher ratio produces a stronger coefficient of reproducibility which indicates a more predictable acquisition order across the items under study.

Guttman’s scalogram technique has been used to examine the order of difficulty and acquisition for several types of motor behaviors. DeOreo (1976) studied the order that children acquire balance task items. Prior to the current study, Harrod (Harrod, 1990; Harrod & Langendorfer, 1991) was the only individual to examine the order of acquisition for swimming skills, specifically beginner swim items. Harrod undertook her study to test whether a traditional order of beginner skills proposed by the American Red Cross (1981) was, in fact, the optimal order in which to introduce those swim items. One important result included the discovery that the ten-second breath holding item (American Red Cross, 1981) was one of the hardest beginner skills and should either be shortened or be taught much later to beginners. She also identified that front and back gliding skills were passed by more children than were front and back float items, suggesting that for children it was easier to move and glide than to float motionless. As a result of Harrod’s work, the American Red Cross did revise the order in which some beginner swimming skills (e.g., breath holding) were taught (American Red Cross, 1992).

The purpose for the current study was to replicate the findings of Harrod (1990; Harrod & Langendorfer, 1991) with an older age sample and with slightly different swimming items. The study was conducted because the American Red Cross was once again in the midst of revising the learn-to-swim program. The organization has made a commitment to base their practices more closely on evidence-based literature.

METHOD

College students already enrolled in academic credit-bearing instructional swimming classes at Bowling Green State University were recruited to participate in our study. From the approximately sixty students enrolled in the courses while we conducted the study, thirty-eight students initially volunteered and thirty-one ($n_f = 17$ females; $n_m = 14$ males) completed testing for all thirteen skill items. Because testing occurred across multiple days, several original volunteers completed only some of the tasks due to absenteeism and were eliminated from the data analysis.

Before beginning data collection for the study, the authors submitted a proposal and received approval from the University’s institutional research review board, called the Human Subjects Review Board (HSRB). Prior to participation in the study, each student completed an informed consent form and investigators answered any of questions. Specifically, each student was reminded that participation was completely voluntary, would not influence their grade in the course, and they could end participation at any time with no penalties or consequences.

The thirteen specific swimming skill items tested and performance criteria are identified in Table 1. They ranged from several typical beginner skills (Red Cross Levels 1 and 2) such as breath holding, prone and supine floats and gliding to performing more advanced strokes (Levels 3, 4, 5) such as front and back crawl, breaststroke, elementary backstroke, and sidestroke. The specific performance criteria employed in judging the successful achievement of each skill were those described by the American Red Cross in their Swimming and Water Safety Instructor’s Manual (2004).
Table 1. List of swimming skill items tested in the current study and their criterion standards.

<table>
<thead>
<tr>
<th>Swim Test Item</th>
<th>Abbr.</th>
<th>Criterion Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breath holding</td>
<td>Breath</td>
<td>Submerge entire head and remain submerged a minimum of 3 seconds</td>
</tr>
<tr>
<td>Prone float</td>
<td>P float</td>
<td>Float on your front for as long as possible, at least 5 seconds</td>
</tr>
<tr>
<td>Prone glide</td>
<td>P glide</td>
<td>Push off on your front and glide forward at least two body lengths</td>
</tr>
<tr>
<td>Back float</td>
<td>B float</td>
<td>Float on your back for as long as possible, at least 5 seconds</td>
</tr>
<tr>
<td>Back glide</td>
<td>B glide</td>
<td>Push off on your back and glide forward at least two body lengths</td>
</tr>
<tr>
<td>Combined stroke alternating arm action</td>
<td>Comb Alt</td>
<td>Swim on your front kicking your feet and pulling with your arms, alternating (taking turns) for 10 yds</td>
</tr>
<tr>
<td>Dolphin kick</td>
<td>Dol Kick</td>
<td>Hold on to this kick board and kick using up-down dolphin kick for 10 yards</td>
</tr>
<tr>
<td>Combined stroke simultaneous arm action</td>
<td>Comb Sim</td>
<td>Swim on your front kicking your feet and pulling with your arms at the same time for 10 yards</td>
</tr>
<tr>
<td>Front crawl</td>
<td>Fr Crwl</td>
<td>Swim the front crawl (freestyle) with rotary breathing for 15 yards</td>
</tr>
<tr>
<td>Back crawl</td>
<td>Bk Crwl</td>
<td>Swim the back crawl (backstroke) for 15 yards</td>
</tr>
<tr>
<td>Elementary backstroke</td>
<td>El Back</td>
<td>Swim the elementary backstroke with a whip kick and glide for 15 yards</td>
</tr>
<tr>
<td>Breaststroke</td>
<td>Brst</td>
<td>Swim the breaststroke using pull, breathe, kick, glide for 15 yards</td>
</tr>
<tr>
<td>Sidestroke</td>
<td>Side</td>
<td>Swim the sidestroke with alternating arms, scissor kick, and glide for 15 yards</td>
</tr>
</tbody>
</table>

The testing occurred during regular class times on Tuesday and Thursday mornings over a three week period during the middle of a fall academic semester. The instructor of the swim classes who was also the assistant coach for the women’s varsity competitive swim team encouraged students to participate in our study and allowed them to come in pairs or threesomes to the shallow end (~ 1 yard or 0.91 m) depth of the indoor 50 meter (54.7 yards) x 25 yard (22.86 m) University swimming pool while the remainder of the class participated in normal class activities in the middle and deep ends of the pool. The pool water temperatures were held constant at 26.7o C. Air temperature was a consistent 29.4o C.

The shallow end of the large swimming pool was set up as three testing stations to which participants rotated in pairs or threesomes. Station one included breath holding, prone float, prone glide, supine float, and supine glide items. Station two tested combined stroke on the front using alternating arms, combined stroke on the front using simultaneous arms, dolphin kick with a kick board for 10 yards, plus front and back crawl strokes for 15 yards. At station three participants were asked to perform the breaststroke, elementary backstroke, and side stroke, each for at least 15 years. Test administrators asked each student to attempt each skill three times for purpose of establishing reliability. If students passed their first two attempts, the third attempt was omitted.

Performance of the skills at each station were recorded by a video camcorder (either SONY or Panasonic models) affixed to a tripod that allowed the tester to pan the camera to follow participants as they moved. Each video camcorder recorded the swimming skills on a miniDV tape for later replay on a video recorder and large screen monitor. Video capture rate was 30 frames per second with the electronic shutter on the automatic setting.

Student participants started at any of the three stations and rotated to the next open station. A set order of testing purposefully was not followed to ensure that no testing order affect occurred. If students became fatigued while performing any skill, they were permitted as much time as necessary to recover. If necessary, they were allowed to complete skills during the next class period two or five days later to eliminate the potential impact of fatigue on the results.

Upon completion of the data collection, the investigators created a content analysis for each of the miniDV videotapes that served as an index to locate individual students. Both investigators then sampled approximately 10 trials of each skill item and independently observed and classified the performance as successful (pass) or unsuccessful (fail) according to the American Red Cross (2004) criteria (Table 1). We compared results and calculated the proportion of exact agreement to ensure that we were in agreement more than P = 0.80, or 80% exact agreement. When those levels of inter-rater objectivity were assured, the second investigator viewed all the trials for all 31 participants and classified them as either successful or unsuccessful. Subsequently, successful performances (on at least two out of three trials) were recorded in a spreadsheet as ones (1). Unsuccessful attempts (at least two of three trials that did not reach the criterion standard) were placed in the spreadsheet as zeros (0).

RESULTS

Guttman’s (1950) scalogram matrix orders both participants and test items according to the number of successful completions. In other words, the least successful (and presumably least skilled and experienced) participant was that individual who completed the fewest skill items. The most successful participant was the person who successfully performed the most items. Conversely, the easiest item was that which was completed by the most participants and the most difficult item was the one completed by the fewest participants.

The swimming skill items passed most frequently by the current sample of college students were breath holding, combined stroke on the front with alternating arms, and front crawl which were passed by all participants. The swimming skill items that were passed least frequently (by only 81-84% of the participants) were the prone and supine glides, elementary backstroke, and sidestroke. Slightly more than half (16) of the participants successfully passed all items. Only one participant passed fewer than ten items (i.e., nine). On average, participants passed 12.2 of the 15 items. The overall coefficient of reproducibility for the order of items was CR = 0.93.

DISCUSSION

The results of the scalogram analysis performed in the current study indicated that this selected set of thirteen swimming skill items could be quite reliably performed in the order proposed by the 2004 American Red Cross learn-to-swim program because of the relatively high coefficient of reproducibility in which CR = 0.93. This means that three second breath holding, front and back floating for five seconds, followed by a 10 yard combined stroke on the front using alternating arms are the least difficult swimming items that can be introduced first, at least to young adult swimmers. Front crawl stroke also can be introduced reasonably early in the learn-to-swim process for young adults. Other strokes appear to be more difficult, including the resting strokes of elementary backstroke and sidestroke. Described in developmental terms, these thirteen swimming items identified a reasonably robust inter-test developmental sequence. In Harrod’s (1990; Harrod & Langendorfer, 1991) previous scalogram study that tested some of these same items (albeit using 1981 Red Cross item descriptions) with elementary-aged children, the range of coefficients of reproducibility was CR = 0.64 to 0.81. At least for the young adult sample tested in the current study, no higher coefficient of reproducibility could be obtained by altering the proposed order.

The primary difference between the results of the current study and those of Harrod (1990; Harrod & Langendorfer, 1991) was that the prone (front) and supine (back) floating items were indeed accomplished more successfully by the young adults than they were by the children. Harrod discovered that children appeared to more easily perform a front and back glide in which they could move their arms and...
legs than they could float motionless on their front or back. Despite Harrod’s findings, the Red Cross never did introduce gliding skills prior to floating in their learn-to-swim program (American Red Cross, 1992). At least with adults, it appears that floating probably can be taught prior to introducing the gliding skills. Interestingly, the two gliding skill items were as difficult for the current sample to perform as were the elementary backstroke and sidestroke. This difficulty is somewhat surprising since both front and back gliding nominally would appear to be much less complicated and difficult items than the two resting strokes.

Based upon these results, the authors could not suggest to the American Red Cross that there was any evidence-based support to alter the order in which the thirteen selected skill items ought to be presented in the revised 2009 American Red Cross learn-to-swim program. The study obviously did not test all pertinent skill items involved in the Red Cross’ learn-to-swim program and therefore the results should not be interpreted to apply to the validity of the order for skills in the entire learn-to-swim program. Because the current sample was limited to a relatively small convenience sample of normally-abled young adult college students, it also is not possible to suggest that even the order of these items with the strong coefficient of reproducibility actually applies to other individuals such as preschool or elementary-age children or to individuals who may be differently-abled. Samples drawn from other specific populations would be required to understand whether this order of acquisition, and by extension, instructional order, should be considered to be universal or whether the order is unique to different age and ability groups. Understanding how much variability in order is associated with different ages and ability groups would be crucial pieces of information to support future evidence-based revisions to learn-to-swim programs such as the American Red Cross.

The study and its results have some very definite limitations. A sample size of thirty-one was relatively small which limited the statistical power with which the descriptive scalogram could identify variability in the order of item difficulty. We initially had intended to test all sixty class participants, but some students did not volunteer while others were absent some days and did not complete all items. The sample was definitely a convenience sample which meant that some of the less skilled individuals opted not to participate, skewing the participant skill levels. The results of the study revealed several limitations in the conduct of the study (e.g., relatively small convenience sample, limited skill and age range of participants) as well as raised questions about the robustness of the scalogram technique itself and the interpretation of the coefficient of reproducibility. The authors have proposed several subsequent studies to clarify the technique and interpretation of the results.

CONCLUSION

The current study employed Guttman’s (1950) descriptive scalogram technique to examine the validity of swim skill item order of acquisition in a small convenience sample of young adults. The instructional order of thirteen swimming skills used by the 2004 American Red Cross learn-to-swim program was tested using a scalogram. The Red Cross order of the thirteen swimming items produced a very strong coefficient of reproducibility (CR = 0.93) and provided some evidence-based support for the Red Cross to continue presenting those swimming items in a similar order in their learn-to-swim programs. The results of the study revealed several limitations in the conduct of the study (e.g., relatively small convenience sample, limited skill and age range of participants) as well as raised questions about the robustness of the scalogram technique itself and the interpretation of the coefficient of reproducibility. The authors have proposed several subsequent studies to clarify the technique and interpretation of the results.

REFERENCES


**ACKNOWLEDGEMENTS**

The data for this research study were collected as part of KNS 470, Independent Study in Kinesiology; conducted while the second author was a student at Bowling Green State University. Both authors acknowledge resources and support provided by the BGSU Center for Undergraduate Research and Scholarship (CURS) that partially funded this study.

**Imagery Training in Young Swimmers: Effects on the Flow State and on Performance**

Scurati, R., Michielon, G., Longo, S., Invernizzi, P.L.

Università degli Studi di Milano, Facoltà di Scienze Motorie, Milan, Italy

Imagery training is the ability to develop mental images that can increase human resources and performances. Flow is one of the peak moments corresponding to a state of optimal experience. This study in young swimmers aimed to observe the effects of specific imagery training on flow state and on swimming performance. Eight young swimmers completed a specific mental training program using imagery as a supplement to three weeks of regular swimming training. A Flow State Scale questionnaire was filled out before and after the training as well as the performance on 100m front crawl stroke was surveyed. The imagery training focused on improving three phases of the front crawl swim stroke and seemed to induce a trend to vary the flow state of the participants. Imagery training did not have effects on swimming performance.

**Key words: Flow, Imagery, mental training**

**INTRODUCTION**

Exercise is related to physical fitness, perception of wellness and quality of life. Positive attitudes, self-esteem and lowering of stress are also induced by sports activities, where psychophysical energies can be focused on a specific target with the maximum of concentration and attention (e.g. in training or events), in the so called “peak moments” (Berger et al., 2001). Flow is one of these peak moments, corresponding to a state of optimal experience, with a complete attention to the action and a strong balance between challenges and skills (Csikszentmihalyi, 1990). Flow is not necessarily dependent on best performance, being a preparatory phase of it (Muzio et al., 1999).

Flow state can be measured through the Flow State Scale (FSS) questionnaire (Jackson, 1996), based on 36 items evaluated using a 5 point Likert scale, related to the 9 fundamentals or dimensions (4 items each) in which the Flow state can be subdivided (Csikszentmihalyi, 1990).

Dimensions in the FSS (Muzio et al., 1999) are: D1, balance between the perceived challenge and the perceived personal skills required to act; D2, union between action and awareness (athlete is fully focused on the task, no panic or effort, there is only naturalness); D3, clarity of targets (athlete can visualize in advance the performance); D4, instantaneous feedback (inner or outer); D5, concentration on the task avoiding distractions; D6, Sense of control (management of the self-esteem improving confidence, quiet and empowerment and reducing the fear of failure); D7, lack of ones self awareness; D8, destructuring of time (athlete perceives the time expanding or condensing); D9, the autotelic experience (athlete is motivated in doing the activity just for pleasure, for fun or because it is exciting).

Imagery training is the ability to develop mental images that can increase human resources and performances exerting a great effect on mind, feelings and behaviours (Hogg, 2000). Images built during the mental training have to be very precise, clear and detailed and they can be obtained through the aid of the kinaesthetic abilities. An inner or an outer vision can be built: in the inner vision, the kinaesthetic acuity leads athletes in imaging the actions as really performed; in the outer vision, the athlete watches himself acting as through the eyes of a third person or as in a movie.

Mental training can transform negative images into positive ones, aiding athletes to overcome anxiety, stress, technical and tactical troubles, difficulty in concentration on the performance (e.g. visualizing during the mental training some memories of a situation experienced during a previous event).
Because the visualization of a movement triggers activities in some areas of the brain's motor cortex, repeated imagery training (movements or specific images closely related to the movements) could induce improvements in the performance.

This study in young swimmers aimed to observe the effects of a specific imagery training on the flow state and on their swimming performance.

**METHOD**

Sixteen young swimmers (7 females and 9 males) volunteered for the study. Participants were divided into two homogeneous groups (eight participants each) randomly assigned to the Experimental or Control group: i. Experimental group (mean±SD, age 13.0±0.53 years, weight 55.38±7.95 kg, height 165±8 cm, BMI 20.19±1.21 kg·m⁻²); ii. Control group (mean±SD, age 13.25±1.04 years, weight 53.8±7.95 kg, height 161±7 cm, BMI 20.21±1.66 kg·m⁻²).

Experimental participants were first introduced to the imagery training by means of a preparatory explanation and an information leaflet. Following the instructions in the leaflet, they self-practiced a number of exercises at home for 10 days aimed to manage the imagery abilities and the ability to overcome a negative situation (e.g.: to visualize a friend sitting in front of you and practice focusing on a number of details and emotions; to imagine a weak lamp hang in front of you, increasing and reducing in intensity; to select an object and to focus on it through an inner or an outer perspective; to focus on a technical swimming action, on muscular feelings, trying to imagine the same action at the maximum expected power during events; to visualize the same fellow of the first exercise walking around the room and speaking to the people and to yourself). Subjects were also asked to watch the illustrations (Figure 1) of three very important movements of swimming events: the start phase (diving in the fastest and most reactive way like a dolphin), the swimming phase (swimming to escape from a shark) and the turns (inverting the swimming direction as fast as possible like a missile).

After this preparatory period, the experimental subjects conducted specific mental training on imagery to supplement the swimming training. They were invited to continue to practice imagery at home and an additional imagery exercise was carried out during swimming sessions: 20 to 30 minutes per session, subjects were lead by the coach in rehearsing the illustrations. They were also asked to perform at the maximum level the elements of the weekly swimming training that were scheduled as: starts (on Monday), swimming speed (on Tuesday), turns (on Wednesday), starts and swimming (on Thursday), start, swimming and turns (on Friday).

The swimmers attended a three week training program, for two hours per day. The control group performed the same volume and training program as the experimental group, but no sort of mental training was carried out.

The Flow State Scale questionnaire was filled out by subjects before and after the three weeks of swimming training as well as the performance on 100m front crawl stroke was surveyed.

Statistical analyses were carried out by SPSS 13.0® software, setting p<0.05. The normal distribution of the data was verified through Shapiro-Wilk test.

Where the normality assumption was found, analysis of the variance (ANOVA) 2x2 design was applied: 2 levels for the time factor (pre- and post) and 2 levels for the group factor. When differences of means were found, a paired t-test comparison was applied.

When the normality assumption was not verified, the non parametric Mann-Whitney, Friedman and Wilcoxon tests were applied. Bonferroni adjustment was used for multiple comparisons when necessary.

**RESULTS**

In the Experimental subjects a lack of reliability was found in the Flow State Scale answers related to the dimensions D5 and D8. The same was found in the Control group who showed a poor reliability also in the post D7 dimension. For this reason, results in these dimensions were not considered.

No differences were found in the pre-post comparison in the Control group, whereas a significant difference (p<0.05) was noticed in some answers of the Experimental subjects: A30 (pre Vs. post scores, mean±SD; 3.25±0.71 Vs. 4.75±0.46) referring to the D3 dimension; A6 (3.25±0.71 Vs. 3.88±0.35) and A24 (3.13±0.99 Vs. 3.88±0.64) referring to the D6 dimension; A34 (3.75±1.16 Vs. 3.25±1.04) referring to the D7 dimension; A36 (3.75±0.89 Vs. 3.25±1.04) referring to the D9 dimension.

The common tendency found only in the Experimental subjects in having any Imagery training effects on the FSS is shown in Figures 2 and 3.

In the 100m front crawl stroke no differences (p>0.05) were found between the Experimental subjects and the Control or between the pre- and post- training in the intra-group comparisons.

![Figure 1. Illustrations aimed to drill the imagery associated with the important phases of swimming contained in the leaflet for the Experimental subjects](image1)

![Figure 2. Pre-post comparison of the Flow State Scale results in the Experimental subjects. Mean data are shown, grouped by FSS dimensions. Dimension into brackets indicate answers showing low reliability.](image2)
DISCUSSION
The results showed effects due to the imagery training. The graph referring to the pre-post training of the Experimental swimmers (Figure 2) compared to the one related to the Control swimmers (Figure 3) evidence the flow state variations after the Imagery training.

In particular, a significant relevance was found in the flow dimensions D3 (clarity of targets) and D6 (sense of control). Imagery training aided athletes in identifying a specific target in order to increase the motivation in reaching it. A low or a lack of motivation leads to an excessive relaxation often causing absence of energy and anxiety. Similarly, the mental training could have improved the sense of control of the Experimental subjects that allow them to better focus on their goals and to manage their self-esteem.

The negative variations in the D7 (lack of ones self awareness) and D9 (the autotelic experience) could be due to the fact that the specific imagery training employed in this study would have forced the swimmers to a voluntary execution of the technical movement illustrated instead of to execute automatic actions. A peculiarity of automatic movements is the lack of central control, with a high intensity of the performances and a low level of conscious control (Logan, 1985).

Referring to the lack of the repeatability found in the answers related to the dimension D5 (concentration on the task avoiding distractions) of the FSS, it was hypothesized that young swimmers could have difficulties in concentration and could be quite liable to disturbance.

In swimming performance no significant differences were found between the Experimental subjects and the Control or between the pre- and post-training in the intra-group comparisons. Even if the relative short time period of imagery training (three weeks daily) would be suitable to induce effects on the performance as a result of technical and cinematic improvements, imagery training did not affect swimming performance probably because flow and performance are not necessarily proportional (Muzio et al., 1999). Moreover, the age of the subjects could have relationships with the effects on imagery training.

CONCLUSION
In young swimmers, three weeks of imagery training focused on improving three phases of a front crawl swim shows that some flow dimensions vary in the flow state of subjects. Imagery training did not have an effect on swimming performance (100m front crawl stroke). An extended training over a longer period and with swimmers of different ages is advised in order to complete the results of this study.

REFERENCES
Shallow or Deep Water for Adjustment? A Study in Children Aged 3 to 6 Years

Scurati, R., Michielon, G., Longo, S., Invernizzi, P.L.

Università degli Studi di Milano, Facoltà di Scienze Motorie, Milan, Italy

In a learn-to-swim programme, the question of what is the best environmental condition for aquatic adjustment. The choice could depend on the depth of the swimming facilities or on the swimming teaching methodology. This study aimed to compare the outcomes of water adjustment carried out in deep or shallow water in 3 to 6 year old children. Children practicing the learning programme in deep water obtained a higher mean score, but not significantly different than the children having a shallow water adjustment programme. The depth of the swimming pool seems to not significantly affect the results. Children can approach guided experiences equally either in shallow or deep water to learn the swimming basic skills and independence in the water, with no differences in the rate of acquisition or in the quality of the skills.

Key words: motor learning, water adjustment, beginners, deep water, aquatic skills

INTRODUCTION

Among more frequent questions swimming teachers have to answer when planning learn-to-swim programme is, “what is the best environmental condition for teaching beginners?” Frequently, teachers have no alternative and have to adapt to the swimming facilities they are working in, but if the environmental conditions allow it, which choice between starting a swimming experience in deep or shallow water is the best one?

In the literature there are several studies and theories about swimming teaching methods. Referring to the best age for starting swimming learning, the age of five to six years seems to be suitable for teaching swimming front crawl stroke (Blanksby et al., 1995). At 4 years of age, children show adequate abilities to acquire good levels of water confidence or basic aquatic locomotion skills, whereas earlier water experience does not necessarily lead to a faster gain of specific basic skills (Parker et al., 1997).

The influence of aids on water first experiences has also been studied. No differences were found in learning and improving the front crawl kicking either using just a kickboard or employing multiple various aids (Blanksby et al., 1999). Moreover, in advanced beginners flotation suits do not show evidence of influence on floating or on gliding abilities (Kendall, 2009a) as well as on the enhancement of the swimming abilities (Kendall, 2009b).

Authors considered at first the depth of the water and advanced learn-to-swim programmes based on activities in shallow water (Langerdorfer & Bruya, 1995; Bucher, 1995) or in deep water (Schmitt, 1992; Cesary et al., 1998).

The aim of this study was to compare the outcomes in 3 to 6 year old children of water adjustment carried out in deep or shallow water.

METHODS

Twenty-two children were selected among the participants of the learn-to-swim programmes in a swimming pool of a village near Milan. Criteria for selection were: i. real age; ii. anthropometric characteristics; iii. swimming skills.

The participants were divided into two groups: group A (mean ± SD, age 4.8 ± 0.7 years, weight 16.76 ± 1.63 kg, height 108 ± 7 cm, BMI 14.23 ± 1.42 kg·m$^{-2}$), group B (mean ± SD, age 5.3 ± 1.4 years, weight 17.23 ± 3.38 kg, height 110 ± 11 cm, BMI 14.07 ± 1.22 kg·m$^{-2}$).

Swimming skills were the same for all subjects: no previous experience in learn-to-swim programmes, no specific swimming abilities, no evidence of preexisting conditions causing problems during water activities.

Each group was assigned to a learn-to-swim programme aimed at a first experience and adjustment to water activities corresponding to the first level of a learn to swim programme (Table 1), according to the progression showed in the Table 2, practiced in the shallow or deep water condition: group A in shallow water (SW), group B in deep water (DW).

Sixteen classes 60-minutes long were attended by the children. Each class was structured as follows: 5 to 10 minutes of warm-up in a gym using simple games or exercises; 40 to 45 minutes of various targeted games and practices with an open multi-lateral approach in order to maintain high attention and motivation and to achieve the maximum educational effect (sometimes more than one step at a time, see Table 2); 5 to 10 minutes of free games, jumps and dives. Flotation supports were employed when necessary.

The SW group transferred into the deep water during the two last classes for a short period of adaptation to the new environment because the final evaluation had to be executed in the deep water.

Scores were assigned according to the presence of level 1 indicators in Table 3.

Table 1. Complete learn to swim program.

<table>
<thead>
<tr>
<th>Level</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Comfort and independence in the water</td>
</tr>
<tr>
<td>2</td>
<td>Displacing by kicking on the back and managing the side breathing in prone position</td>
</tr>
<tr>
<td>3</td>
<td>Elementary front crawl and backstroke swimming</td>
</tr>
<tr>
<td>4</td>
<td>Front crawl and backstroke with continuity and breaststroke leg kicking</td>
</tr>
<tr>
<td>5</td>
<td>Complete breaststroke and elementary turns</td>
</tr>
<tr>
<td>6</td>
<td>All strokes and competitive starts and turns</td>
</tr>
</tbody>
</table>

Table 2. Targets of the 1st level of the swimming program.

<table>
<thead>
<tr>
<th>Progression</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Discovering the aquatic environment and first contact with the water</td>
</tr>
<tr>
<td>2</td>
<td>Displacing with supports / holds</td>
</tr>
<tr>
<td>3</td>
<td>Head submerging (with closed and open eyes)</td>
</tr>
<tr>
<td>4</td>
<td>Breathing in static and dynamic attitudes</td>
</tr>
<tr>
<td>5</td>
<td>Static and dynamic floating, with or without aids</td>
</tr>
<tr>
<td>6</td>
<td>Static and dynamic floating, with or without aids, adding breathing</td>
</tr>
<tr>
<td>7</td>
<td>Propelling with and without flotation supports</td>
</tr>
<tr>
<td>8</td>
<td>Jumping and diving</td>
</tr>
</tbody>
</table>

Table 3. Table of evaluation of the complete swimming learning program.

<table>
<thead>
<tr>
<th>Level</th>
<th>Sub-level</th>
<th>Check-list (test)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+</td>
<td>Swimming leaning on a floating support, by kicking in prone position and immersing the face.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>++</td>
<td>Swimming with a kickboard (or similar), by kicking in prone or supine position and immersing the face managing an elementary breathing.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+++</td>
<td>Full independence in the water. Short displacement in prone and supine position without any floating support. Continuous breathing at the border. Dropping and diving in free techniques.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>+</td>
<td>Gliding in prone position and in supine position (arms along the body) by correct kicking.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>++</td>
<td>Performing a series of front crawl arm strokes breathing and rolling on the back. Performing 25m on the back, arms along the body.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+++</td>
<td>Kicking with a kickboard or a floating aid, no arm stroke, breathing on the side. Backstroke keeping the arms straight.</td>
<td></td>
</tr>
</tbody>
</table>
SW or DW aquatic activities. No significant differences were found (p=0.20).

Figure 1. Comparison between water adjustment carried out through SW and DW. No significant differences were found (p=0.20).

Statistical analyses were carried out using SPSS 13.0® software. Mann-Whitney non-parametric statistics was applied in order to compare the results between SW and DW.

RESULTS
The results of the evaluation of the abilities children acquired in SW or DW learn-to-swim activities are reported in the Figure 1. No significant differences were found (p=0.20).

<table>
<thead>
<tr>
<th>Level</th>
<th>Sub-level</th>
<th>Check-list (test)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>+</td>
<td>Swimming front crawl with a floatation aid; backstroke with alternate arm stroke; diving from a kneeling position.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>++</td>
<td>Swimming front crawl for a little while without supports, alternate arm stroke and side breathing; backstroke pausing over the head.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>+++</td>
<td>Elementary front crawl stroke, one side breathing; elementary backstroke.</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>Swimming alternating four arm strokes on front crawl and backstroke.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>++</td>
<td>25m complete and continuous front crawl and backstroke.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>+++</td>
<td>Breaststroke kicks with a kickboard. 25m complete and continuous front crawl and backstroke.</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>+</td>
<td>Breaststroke kicking both in prone and supine position without kickboards.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>++</td>
<td>25m complete and continuous front crawl and backstroke. Complete breaststroke. Starting with dive.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>+++</td>
<td>Complete front crawl, backstroke and breaststroke with elementary turns.</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>+</td>
<td>Complete front crawl, backstroke and breaststroke; coordination exercises (e.g. arms like in breaststroke and legs like in front crawl).</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>++</td>
<td>Complete swimming front crawl, backstroke, breaststroke and butterfly. Front crawl and backstroke flip turns.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>+++</td>
<td>100 relays with start dive and turns.</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 1. Comparison between water adjustment carried out through SW or DW aquatic activities. No significant differences were found (p=0.20).

DISCUSSION
Children practicing the learning program in the deep water obtained a higher mean score, but not significantly different than the children having a shallow water adjustment program. Probably this little difference could be due to the fact that SW children have to get acquainted to the new environment (they moved into the deep swimming pool only two classes before the final evaluation was carried out in deep water), whereas DW children performed the test in the same situation they managed since the first class. Authors claiming the suitability of the deep water adjustment (Schmitt, 1992; Cesary et al., 1998) point out that children do not have to switch from a simple situation (shallow water) to a more difficult one, starting the adjustment process again.

Children experienced in the shallow water could need a readjustment adaptation of their aquatic motor skills when transferred to deep water, and occasionally even suffer a regression.

Shallow water activities led to similar results as deep water adjustment, supporting authors asserting that this experience occurs in a simple condition with more stable supports and with the possibility to do more dynamic exercises (Langendorfer & Bruya, 1995; Bucher, 1995). Thus, deep water would be an unfriendly environment, where instability of support, and a more adverse psychological situation could represent different issues.

All authors agree with similar progressions of the complete swimming evolution as reported in Table 1. In particular, they largely agree with the sequence in Table 2 referring to the first level of aquatic skills acquisition, whatever the preferred environment for starting the water activities is.

As pointed out by Magill (1988), the maturation level of children and the motivation are very important elements in learning the motor skills, which may apply to the current situation.

CONCLUSION
In children 3 to 6 years old, the depth of the swimming pool does not affect the learning of the first level of aquatic skills (adjustment and independence in the water).

Guided experiences both in shallow and deep water can lead to basic swimming skills with no differences in the rate of learning and improving skills or in the quality of the skills.

REFERENCES


The Effect of a Target Sound Made by a Model Swimmer’s Dolphin Kick Movement on Another Swimmer’s Dolphin Kick Performance

Shimojo, H.1, Ichikawa, H.2, Tsubakimoto, S.1, Takagi, H.1

1 Graduate School of Comprehensive Human Sciences, University of Tsukuba, Tsukuba City, Japan
2 Department of Sports Information, Japan Institute of Sports Sciences, Tokyo, Japan

The aim of this study was to determine the effect of a target sound made by a model swimmer’s dolphin kick movement on another swimmer’s dolphin kick performance. Fifteen competitive swimmers participated in this study. Subjects were required to swim using a dolphin kick while listening to the target sound as closely as possible. The aim of the task was to determine whether the timing and displacement of their dolphin kick would change, and the degree to which the change would be retained without the sound. After swimming with sound, subjects experienced a decrease in timing error relative to their performance without sound for up to 300 s, but displacement error did not decrease significantly. The results also suggested that with auditory models, which have been particularly effective for timing patterns, it would be hard to recognize displacement differences.

Key words: Dolphin kick, motor learning, auditory model

INTRODUCTION

In swimming training, the swimmer must enhance power and endurance for good performance, which involves efficient movement. Such high performance movement must be achieved through effective motor learning.

Many motor learning and motor control studies were conducted in sports psychology and neuroscience. Target tracking tasks, require the subject to move a cursor utilizing a mouse to track moving target point on display. The trajectory error of trials was used to evaluate performance. Yamamoto et al. (2007) reported target tracking tasks utilizing an auditory model, where the movement target on display was synchronized with stereo sounds expressing right or left by sound volume control. The subject was required to control the mouse to get close to the moving target following auditory model with the eyes closed. They suggested that the auditory model could be used in real world sports training.

Baudry et al. (2006) reported that an auditory concurrent feedback on cyclic movement was effective in motor learning and performance. Wang and Hart (2005) reported that an auditory model that was an effective method to enhance the learning of swimming movement timing in beginner classes. But an auditory model has not been attempted in expert swimmers. If an auditory model could affect motor learning to create the skilled movement required for high performance in competitive swimming, coaches and swimmers could use such a method to enable swimmers to improve each other’s performance in training. The purpose of this study, therefore, was to determine the effect of a target sound produced by a model swimmer’s dolphin kick movement on another swimmer’s dolphin kick performance.

METHOD

Fifteen competitive swimmers (ten males and five females) participated in this study. They were aged 22.1 ± 4.7 years and all subjects had more than ten years of experience in competitive swimming and had normal hearing. An informed consent was obtained from all subjects before their participation in this study.

Before this study, one model swimmer swam with the dolphin kick in the pool at sub-maximal speed (1 m/s) for getting two-dimensional coordinates by filming. After a single kick phase was chosen, coordinates of the swimmer’s vertical range were exchanged to relative coordinates (% height). We created a “target sound” that indicating displacement differences expressed as sound frequency scales in the range of 300-900 Hz converted by the coordinates. Because “Concert A” or “Middle A” is the 440 Hz tone that serves as the standard for musical pitch and is used in instrument tuning, the range of 300-900 Hz was adopted with an average of 440Hz for the “target sound”. Prior to this study, it had been confirmed whether the model swimmer could replay the same movement while listening to the target sound in the pretest.

After it was explained to subjects what the target sound indicated, the subjects were required to swim with the dolphin kick after a wall push start to a distance of 10m while listening to the target sound, and to “track” the target swimmer’s movement. The task was to swim “tracking” the movement of the target as well as possible. After the normal dolphin kick test that required the subject to swim at 80 % or less effort, the height of toe displacement in the dolphin kick was narrow, were obtained from the target sound. Task 1 was conducted the 75% and the 50% target sound were used randomly for ten trials, and the effect was investigated from differences between pre 1 and post 1 trials with target sound.

The aim of Task 2 was to see whether the swimmer’s dolphin kick would retain any improvements without the target sound. Task 2 was conducted with the target sound for ten sessions. The effect was investigated from differences between pre2, post2, post3 (60 s later), post4 (120 s later) and post5 (300 s later) with no sound requiring the subjects to reproduce the same dolphin kick movement as in Task 1. Figure 1 shows the study protocol.

Data collection was undertaken in an indoor swimming pool whose depth ranged 1.3 m to 1.8 m. Every trial was recorded using four cameras (TK-C1381 Victor Inc., Japan) through an underwater poolside window. Data sampling set 60 Hz. The two-dimensional coordinates of the swimmers’ vertical toe displacement were obtained by a two-dimensional DLT method using motion analysis software (Frame-DIAS 4, DKH Inc., Japan), and were exchanged to relative coordinates (% height) for comparison with the model swimmer. The sound was generated utilizing underwater speakers (MT-70 Toyoonkyo Corp., Japan) that were synchronized with the underwater cameras. Figure 2 shows the evaluation from data collected.

Figure 1. Protocol followed in which subjects were required to use the dolphin kick in every trial.
Two approaches to evaluation were used. One approach applied the idea of Timing Error (TE). The target cycle time was 0.6 s (i.e. the kick phase time). The TE obtained was compared with the trial cycle time and the target cycle time. The second approach employed Displacement Error (DE). The vertical displacement range of the target dolphin kicks were evaluated on a scale of 0 % to 100 %. DE was evaluated by relative Root Mean Square Error (rRMSE) by the displacement of each kick following Fusco and Crétual (2008). Following auditory perception, there is a delay before humans initiate movement (Charles et al., 2001). The DE evaluation was divided into an upward kick and a downward kick without match time. TE and DE were obtained as:

\[ TE (s) = \text{A kick cycle time} - \text{the target cycle time (0.6 s)} \]
\[ DE (\%) = \text{rRMSE} = \frac{1}{N} \sum_{i=1}^{N} \frac{(Y_i - \bar{Y})^2}{\bar{Y}} \]

The closer that the value of TE and DE were to zero, the closer the movement of the subject became to the target movement. The mean of TE and DE for all trials were compared using one-way repeated measures ANOVA followed by the Bonferroni multiple comparison.

**RESULTS**

**Task 1:** Time differences between target cycle time and subject cycle time on the last five trials and total average was calculated by TE. The result of total average of TE in the normal trial was 0.07 ± 0.03 s, pre-test 1 was 0.01 ± 0.01 s and post-test 1 was 0.01 ± 0.01 s. There were significant differences between normal and pre-test 1 (p < .01), normal and post-test 1 (p < .01), but no difference between pre-test 1 and post-test 1. Relative displacement differences between target and subject on last five kick trials and total average was calculated by DE. The result of DE of total average in normal was 14.8 ± 1.39 %, pre-test 1 was 10.74 ± 1.00 % and post-test 1 was 10.87 ± 0.61 %. There were significant differences between normal and pre-test 1 (p < .01), normal and post-test 1 (p < .01), but no difference between pre-test 1 and post-test 1. Figure 3 shows the mean ± standard deviation of TE (left) and DE (right) of the last five dolphin kick trials and the total mean values.

**Task 2:** Time differences between target cycle time and subject cycle time for the last five trials and total average was calculated by TE. The result of TE of total average in pre 2 was 0.02 ± 0.01 s, post 2 was 0.02 ± 0.03 s, post 3 was 0.01 ± 0.02 s, post 4 was 0.02 ± 0.01 s and post 5 was 0.01 ± 0.02 s. There were no differences between trials. Relative displacement differences between target and subject for the last five trials and total average was calculated by DE. The result of DE of total average in pre 2 was 12.1 ± 0.9 %, post 2 was 12.3 ± 0.9 %, post 3 was 13.0 ± 2.7 %, post 4 was 11.3 ± 1.9 % and post 5 was 10.45 ± 0.6 %. There were significant differences between pre 2 and post 5 (p < .01), post 2 and post 5 (p < .01), post 3 and post 5 (p < .05). Figure 4 shows the mean of TE (left) and DE (right) of each last five dolphin kick and the total mean values.
DISCUSSION

Task 1: The difference between normal and pre-test 1 on timing and displacement indicated that the swimmer could change the movement immediately while listening to the sound (see Figure 3). After Task 1, there was no significant difference between pre-test 1 and post-test 1. Although DE values in pre 1 and post 1 both were lower than the normal, our expectation was that DE value would decline more in post-test 1 than pre-test 1 because variable sound scales (i.e. 75 % and 50 % sound) could train relative hearing (Miyazaki, 1993) and thus affect the vertical displacement, approximating the target movement. Task 1 would indicate that changing sound scale randomly (meaning changing height of dolphin kick displacement) has no effect for dolphin kick movement.

Task 2: The results of TE on post2, post3, post4 and post5 indicated that the subjects retained the approximate dolphin kick timing to the target without the sound (see Figure 4). The auditory model has been a quite effective aid for timing patterns (Charles et al., 2001). If a coach wishes to change a swimmer's movement, a target sound could have an effect on his/her timing or help to create a constant tempo during training. The result of DE, in spite of the displacement of the target swimmer movement expressed on a sound scale, there was no difference after Task 2. There were, however, significant differences between three trials (see Figure 4). It would appear that the subject's concentration on sound retention in Task 2 did not influence his/her performance in post2, but a non-auditory environment made the swimmer focus on receiving kinesthetic feedback. They could later reproduce the movement facilitated by the target sound.

This study indicates that an auditory model can be useful to set a swimming pace or to immediately coordinate timing. The dolphin kick, however, is but one parameter of movement. In the real world of training, the coordination and timing of strokes is based upon several parameters (e.g. kick and arm coordination, arm finish and breath, etc.). A study of the use of auditory models in swimming should focus on parameters that could be coordinated.

In this study, displacement of the toe of the model swimmer was expressed on a sound scale. But the swimmer's displacement error decline from the target appeared a few minute later without the sound (see DE graph on Figure 4). It seems that retention and reproduction of movement were sequential steps according to the motor learning cognitive process (Schmidt, 1991). Listening to the sound scale change and feeling his/her toe displacement from kinesthetic sensation at the same time, for detection of error would be very hard for the swimmer underwater.

CONCLUSION

The target sound was effective for skilled swimmers learning movement timing. Learning displacement was difficult utilizing sound but would be more effective with the learning steps of retention and reproduction in the correct sequence.

REFERENCES


Tendencies in Natural Selection of High Level Young Swimmers

Timakova T.S., Klyuchnikova M.V.

All-Russian Scientific Research Institute of Physical Culture and Sport,
Moscow, Russia

High performance levels in modern sport require great physical and psychological effort from young athletes. Some specialists conduct the early orientation for children with unusual abilities and gifted young ones. This problem has difficulties not only in search of such criteria but also in some social and moral aspects. The aim of the study was to find out facts of change in young swimming leaders, and to discover the reasons of this replacement. The retrospective investigation was done, using data of young swimmers demonstrating high age group performance levels. The analyses have shown a clear tendency to change selection criteria according to age group. Also the differences in biological maturity between swimmers of both sexes were revealed. The greatest variance in age development typology was observed in the age groups of 13-14 years.

Key words: age group, biological age, high level, natural selection, generation.

INTRODUCTION

Over the last 30 years sport has often been criticized for being both institutionalised and for the premature specialisation of children and youth sports. The lower age threshold of children's entry into “organised” sport has dropped from 6–8 to 4-6 years. So an early introduction to training and competition occurs more frequently and in a similar format to the adult paradigm (Schmidt 2001).

According to expert opinion (Brettschneider, 2001, Schmidt 2001) this contributes to the development of early mental fatigue and children's exit from sport. Some researchers feel the need to have different development models of activity for children, such as: a holistic focus and special programs for future champions (Brettschneider 2001). However, when adopting this approach we must employ serious scientific estimation methods in order to assess the potential of each child and teenager. Obviously, early talent identification and an appropriate orientation towards elite sport will avoid a misguided intensification for the majority of youth.

Our research confirms the presence of phenotype features of swimmers with different levels of achievement. However, we believe in the necessity of establishing prognostic criteria for the talent search within sports. In our opinion the main task of preparing young athletes consists of the clear and suitable matching of the proposed training loads to the possibilities of the developing young organism. This primarily concerns problems around the optimization of sports preparation (Bulgakova & Tchebotareva 1999, Klyuchnikova 2000, Timakova 1985).

In this article the research material is presented to display the necessity of making allowances for features of biological development. This permits qualitative management of the selection (talent hunt) and preparation of young swimmers.

METHODS

Retrospective analysis of the best swimmers’ research data in different age groups was done. In total 210 girls and 216 boys covering the age ranges of 12 to 19 years were surveyed. The data were analysed according to their placement in different generations of the country's national swimming teams. One generation of swimmers is from the decade of the 1990s; the other from the first decade of the new century.

Programs of testing included: 1) Anthropometry and the definition of biological age; 2) Swimmers' bio-energetic parameters and functional
abilities in a swimming flume. 3) Special strength training parameters. The biological age of the swimmers (BA) was defined by the authors’ own methods (Timakova 1985, 2006). Depending on a difference between chronologic age (CA) and BA, all swimmers were distributed into 5 groups: R₂ - 1-2 years of retardation on rates of maturation; R₁ - more than 2 years retardation; N - age norm; A₁ - 1-2 years acceleration on rates of maturation; A₂ - acceleration of more than 2 years. Investigation results were processed using standard statistical methods and correlation analysis. Methods of factor-typological description of objects were also used.

RESULTS

The materials in table 1 belong to the contingent of swimmers which displayed the peak of sport achievement in the middle of the 1990s. As we can see, the majority of tested swimmers belong to the 13-14 year age group. With advancing age the number of surveyed girls decreased, whereas the boys did not decrease to the same extent. The most essential differences in this age contingent of girls and boys are shown in the character of biological development.

The norm age development of swimmers across all age groups dominates. However, in the girls’ aged 13-14 we mark the general shift towards delays in puberty. In male groups the trend of shift, on the contrary, is clearly visible as age acceleration. It is characteristic that in cases of acceleration of development this is not found in the senior girls’ age groups at all. Among the high level swimmers of senior age groups the shift in selection related to the tendency of puberty delay is recognized.

Table 1. Swimmer age distribution in relation to personal rates of biological development in %

<table>
<thead>
<tr>
<th>Age</th>
<th>n</th>
<th>R₂</th>
<th>R₁</th>
<th>N</th>
<th>A₁</th>
<th>A₂</th>
<th>tot.</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>3.6</td>
<td>1.2</td>
<td>-</td>
<td>4.8</td>
</tr>
<tr>
<td>13</td>
<td>19</td>
<td>3.6</td>
<td>4.8</td>
<td>9.6</td>
<td>4.8</td>
<td>-</td>
<td>22.9</td>
</tr>
<tr>
<td>14</td>
<td>37</td>
<td>6.0</td>
<td>16.3</td>
<td>1928</td>
<td>3.0</td>
<td>-</td>
<td>44.6</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>3.6</td>
<td>6.0</td>
<td>2.4</td>
<td>-</td>
<td>-</td>
<td>12.1</td>
</tr>
<tr>
<td>16</td>
<td>8</td>
<td>3.6</td>
<td>6.0</td>
<td>2.4</td>
<td>-</td>
<td>-</td>
<td>9.6</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>2.4</td>
<td>2.4</td>
<td>3.6</td>
<td>-</td>
<td>-</td>
<td>6.0</td>
</tr>
<tr>
<td>total</td>
<td>83</td>
<td>14.5</td>
<td>33.1</td>
<td>43.4</td>
<td>9.1</td>
<td>-</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Boys</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>17</td>
</tr>
<tr>
<td>18</td>
</tr>
<tr>
<td>total</td>
</tr>
</tbody>
</table>

Tables 2 and 3 give the percentage distribution of swimmers in age groups among their top ranked representatives. Data in these tables emphasizes essentially different trends of a natural selection of girls and boys. Among the strongest representatives of the age groups, female types with normal and slowed rate of development dominate. On the contrary, for the best representatives of the male groups a more complicated picture of distribution of the rate of biological development was shown, though the above mentioned tendencies of natural selection prevailed.

In table 4, data of swimmers with achievement peaks in the first decade of the 2000s are presented. Some of these swimmers competed as members of the national team at the Beijing Olympic Games. The characteristic feature of this generation is a representation shift to the senior age groups. Only at the age of 13 years in girls are all three types of biological development equally represented. At the age of 14 and 15 years, the majority of girls correspond to their age norm in terms of development. However, at the age of 16 years the number of girls with a delay of processes of puberty is increased. In the young men, with the increase of years the variety of types of development grows; moreover the shift towards a delay in tempo of puberty strengthens. With the aim to reveal the reasons of such different dynamics of sport achievement growth in swimmers after 14 years of age, we have carried out an auto-classification of all tested parameters. In table 5 the average values of parameters of the largest numerical classes of swimmers are given. The featured particularity of girls in comparison with boys is a higher parameter of sport achievement level. At the same time they do not differ on age, parameters of biological maturity and swimming career duration. As well, girls come short on morpho-functional parameters and especially on integrated characteristics of capacity and efficiency of the aerobic mechanism of power supply, compared with boys. However the ECG analysis of girls before the test was identical to the boys, but girls had higher parameters of cardiovascular system adaptation after testing to the point of exhaustion (in a flume). We want to emphasize that at a later stage, none of the female swimmers from this class reached the level of elite competition.
Table 5. Mean values of parameters in classes of the strongest swimmers at the age of 14 years (M and SD)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualification, nominal units</td>
<td>Girls, n = 21</td>
</tr>
<tr>
<td>CA, months</td>
<td>4.21 ± 0.55</td>
</tr>
<tr>
<td>BA, points</td>
<td>167.05 ± 3.11</td>
</tr>
<tr>
<td>CA – BA, years</td>
<td>4.99 ± 0.79</td>
</tr>
<tr>
<td>Training experience, years</td>
<td>0.37 ± 0.53</td>
</tr>
<tr>
<td>Height, cm</td>
<td>6.07 ± 0.73</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>66.94 ± 5.72</td>
</tr>
<tr>
<td>Chest circumference, cm</td>
<td>5.56 ± 5.20</td>
</tr>
<tr>
<td>Biceps circumference, cm</td>
<td>83.67 ± 3.21</td>
</tr>
<tr>
<td>Hand strength, kg</td>
<td>28.95 ± 4.34</td>
</tr>
<tr>
<td>Lung Capacity, I</td>
<td>3.58 ± 0.42</td>
</tr>
<tr>
<td>Bone mass, kg</td>
<td>9.88 ± 0.91</td>
</tr>
<tr>
<td>Muscle mass, kg</td>
<td>24.37 ± 2.68</td>
</tr>
<tr>
<td>Fat mass, kg</td>
<td>10.16 ± 2.18</td>
</tr>
<tr>
<td>Body proportions</td>
<td></td>
</tr>
<tr>
<td>VO2 max, l / m</td>
<td>2.98 ± 0.59</td>
</tr>
<tr>
<td>LV, l</td>
<td>92.84 ± 22.72</td>
</tr>
<tr>
<td>O2P, ml / beats / min</td>
<td>16.23 ± 3.76</td>
</tr>
</tbody>
</table>

* Biological age in girls = 5 points corresponding to the first menses age.

In table 6 the different ways of categorizing the athletes are presented. Among representatives of these classes there are swimmers who performed at a later date as national swimming team members at the international level. Parameter comparison testifies that the Class of 11 girls-swimmers generally do not differ from the above class analysis concerning chronological and biological age. Nevertheless, they have greater body height and also more athletic constitution characteristics. However, the most important difference for them (from a class of girls in table 5) is that they already at the age of 14 years had more appreciably dimension of physiological characteristics (VO2 max; O2P; LV, etc.). Boys of a class n=16 also have greater height and are biologically more mature. At the same time on body proportions they have a less strong-build and less relative subcutaneous fat.

Table 6. Mean values of analysed parameters in classes of 14 years swimmers of varying characteristics (M and SD)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualification, nominal units</td>
<td>Girls, n = 11</td>
</tr>
<tr>
<td>CA, months</td>
<td>4.18 ± 0.39</td>
</tr>
<tr>
<td>BA, points</td>
<td>167.91 ± 2.58</td>
</tr>
<tr>
<td>CA – BA, years</td>
<td>4.89 ± 0.93</td>
</tr>
<tr>
<td>Training experience, years</td>
<td>-0.42 ± 0.61</td>
</tr>
<tr>
<td>Height, cm</td>
<td>5.64 ± 0.98</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>170.50 ± 3.30</td>
</tr>
<tr>
<td>Chest circumference, cm</td>
<td>56.03 ± 4.64</td>
</tr>
<tr>
<td>Biceps circumference, cm</td>
<td>85.91 ± 4.30</td>
</tr>
<tr>
<td>Hand strength, kg</td>
<td>25.06 ± 1.53</td>
</tr>
<tr>
<td>Lung capacity, I</td>
<td>28.95 ± 6.41</td>
</tr>
<tr>
<td>Bone mass, kg</td>
<td>3.77 ± 0.46</td>
</tr>
<tr>
<td>Muscle mass, kg</td>
<td>9.88 ± 0.91</td>
</tr>
<tr>
<td>Fat mass, kg</td>
<td>25.83 ± 3.32</td>
</tr>
<tr>
<td>Brachium-pelvic index, n.u.</td>
<td>10.61 ± 2.52</td>
</tr>
<tr>
<td>VO2 max, I / l</td>
<td>1.39 ± 0.10</td>
</tr>
<tr>
<td>LV, l</td>
<td>92.84 ± 22.72</td>
</tr>
<tr>
<td>O2P, ml / beats / min</td>
<td>16.23 ± 3.76</td>
</tr>
</tbody>
</table>

DISCUSSION

The analysis carried out reveals a complex process of the best performers changing in their development while in junior swimming. The findings show that swimmers of different characteristics at the age of 13-14 years can achieve success in this sport.

Among girls, swimmers gain advantage over others, through optimum body parameters and excellent adaptation possibilities of their cardiovascular system. It allows them to start intensive training early which does not lead to the necessary development of the aerobic power supply mechanisms. In a quantitative sense independently of the different age-groups and generations the girls with retardation of biological maturity prevailed. Due to peculiarities of their body type and biological development they are inclined to swim in training regimes at a more moderate speed. That helps to boost aerobic capability.(tab.5). There is a further explanation of the preference of selecting swimmers with a body weight deficit and a retardation of puberty signs in girls. Only at the age of 16-17 years the tendency to prevalence of a somatotype according to requirements of modern sports is observed. However the representation of swimmers in these age categories is already at a minimum.

The 12 years of investigation of the same high level swimmers have revealed a decrease in a selection tendency of swimmers with inadequate typology of age-related development for sports aiming at high level achievement. The change in selection trends occurred against an age increase of swimmers of the reserves of the country national team. Accordingly, we have observed a growth of the number of swimmers with optimum body parameters concerning requirements for this particular sport.

Table 6 shows that girls who moved forward at a later age in their sport results did not differ from the strongest swimmers at the age of 14 years. But features of their physical development (tallness, body weight deficit) did not allow coping with high intensity training loads. Training in more optimal regimes was reflected in an advantage in aerobic development possibilities. Thus, research has confirmed the necessity of accounting for age development features and the orientation of training for peak achievements at a later age.

CONCLUSIONS

The competitive activity success at a juvenile age is defined often by a choice of the sports preparation strategy and the influence of swimmer phenotype, including features of biological development. At the age of decisive hormonal shifts (13-14 years) athletes with a certain typology have the advantage. They coincide with the age norm regarding the pace of puberty and possess high adaptive capacities of the cardiovascular system. However, their ability to endure a high intensity training load is negatively reflected in their aerobic development possibilities. Such a situation further affects the dynamics of sport achievement growth. Features of athlete physical development, particularly growth in body height connected with asthenisation does not at this age allow training at high intensity. Accordingly, these swimmers reach their best results at a later age. Their advantage in the development of aerobic power supply mechanisms also promotes this. Therefore, this provides them with the best adaptation to training at higher intensity at a more mature age. These revealed tendencies are more precisely shown in the comparative analysis of the high level young swimmers’ data of different generations.

REFERENCES


A flip turn is a motor action due to a combination of the established competence matching features of postures and situational influences. In general, movements are organized at different cognitive levels including their sensory effects. Every movement is formed by cognitive units, called Basic Action Concepts. The purpose of this study is to elucidate the influence of sensory effects on the biomechanical outcome of the flip turn technique under two different conditions: regular and high tech full swim suit. Methods were biomechanical analysis for the flip turn, a questionnaire for examining the strength of sensory effects, and two sets for the structure dimension analysis–motorics. The results revealed a close connection between the cognitive representation of the sensory based effects of flip turn technique and their biomechanical structure.

Keywords: flip turn, biomechanics, mental representation, swim suit

INTRODUCTION
Swimming is the result of displaced water mass which cause buoyancy and momentum, when set in motion by body movements. Body movements are controlled through cognitive and physiological frameworks. This holds true for activities in aquatic space where the interaction between the body and the surrounding water mass is of importance for an understanding beyond a simple biomechanical approach. Swimming experts know about the relevance of this interaction, but there is only modest scientific evidence concerning the connection of perception and action. Following Bernstein (1967) voluntary movements:

- are stored in memory at different levels as a structure subdivided into details—as an idea or image—but not as chains of details and organized in long term memory as perceptual-cognitive (mental) representations.
- are the result of perceptible events through a mental representation of anticipated characteristic (e.g. sensory) effects.
- means that goals and effects of a movement are stored together and thus each volitional movement is stored effect-coded to achieve movement aims.

Following the hierarchical movement organization of Schack (2004), voluntary movements are represented in the long term memory, including their internal and external effects in units, characterized as Basic Action Concepts (BACs), which are represented at the level of mental control. These BACs are integrated in a hierarchical cognitive architecture. In this context, movements are realizing action goals evoked by motivation, cognition, and emotion, which are grounded on auditory, visual, or kinaesthetic cues (Schack, 2004). According to this cognitive architecture, motor actions are activated and composed of BACs. The internal and external features of BACs are triggered by an image of the voluntary executed movement. Therefore, information from the environment is needed to perform adequately. Links between sensory effects of a movement and corresponding motor commands will be established while executing an action and, moreover, create a specific expertise. In other words, a more adequate image will be created.

A study of the cognitive representation of a swimming technique, including their sensory effects and biomechanics, needs to use an established technique, which in the present study is the flip-turn executed un-
under different conditions (i.e., different swim suits). The general reasoning is as follows: According to the statements of companies advertising high tech full swim suits (which were not banned before 2010) the speed will increase and the feeling will be altered. This is supported by statements of elite swimmers like: “swimming downhill”, “swim like a rocket”, “You lie on top of the water; don’t die in the last metres; you have no pain” or “swim as on a hover cushion”. These statements show that biomechanical changes may not be effects simply due to physical enhancement of the swim suit properties, because they indicate the importance of sensory aspects. According to the hierarchical movement organization theory (Schack, 2004), differences of the motor outcome can be caused by differences of the cognitive representation. Flip turns are important part of every race and differences in the biomechanics of flip turns are expected depending on the swim suit type. Here we investigate to what extent these differences coincide with sensory changes. The question is whether sensory effects can influence the execution of motor programs initiated by mental representation in long term memory, or not.

The purpose of this study is to elucidate the influence of sensory effects on the biomechanical outcome of the flip turn technique under two different conditions: wearing a regular or a full swim suit (covering the whole body surface and possessing slight floating properties).

METHODS
Elite swimmers (N=8: 4 female, 4 male, mean age 19.6 years), members of national or youth national team participating in approx. 10 work-outs per week were informed about the test procedures and gave their consent to participate in this study. They were asked to bring their own regular and competitive high tech swim suits and instructed to execute their flip turns as usual.

The study consisted of 4 parts. First a kinematic analysis of 10 flip turns with subjects wearing both kinds of swim suits was conducted (a). Subsequently, they executed the Structure Dimension Analysis-Motorics procedure (SDA-M, Schack, 2004) with biomechanical BACs (b). Thirdly, they answered a questionnaire regarding their sensory impressions (c), and finally they executed the SDA-M procedure with sensory movement features (d).

The SDA-M procedure reveals mental representations of movements, basically consisting of three steps, and was introduced already in 2006 in swimming research by Ungerechts and Schack. First, the participants make similarity judgements regarding all BACs. Afterwards, the cognitive representation of the movement is illustrated via dendrograms as the result of a hierarchical unweighted pair-group average cluster analysis. At the end, all resulting cluster structures can be compared via an invariance measure.

During the similarity judgements participants make an implicit statement about their movement organization by making decisions based on their own mental representation. Basically there are two options to study the mental representation, either taking biomechanically based BACs or offering sensory movement features (remembering that BACs are functionally closely related to the biomechanics as well as to sensory effects and stored together). The biomechanical BACs used were: fix hands, head on chest, initial butterfly kick, bending legs, feet hit wall, push-off, streamline position, gliding, rotate hip/legs, rotate stomach, and leg movement (BxF splitting procedure). These eleven keywords also represent the allocations used in the B x B approach. The 23 sensory movement features were selected due to feel for own body (rushing of water, look at the pool bottom, estimate distance to the wall, pressure on stomach, pressure on the soles increases, vibration of muscles, vibration of skin, tension in neck muscles, keep equilibrium, leg extension, pressure on shanks, pressure on both sides of the legs, alternatively), feel for speed (keep speed, rotational speed increases, maximum change of body speed, renewed speed increases, gliding velocity decreases) and reactions of the water (wave drag, drag effects start, drag effects release, lowest drag, pushing water mass, buoyancy). They formed the keywords for the BxF splitting procedure.

During the splitting procedure the participants judge whether the two presented BACs (respectively the presented BAC and the sensory movement feature) are related to each other, or not. Using a BxB approach, eleven BACs and eleven biomechanical allocations are presented. Using a BxF approach the swimmers were asked to relate all of 23 sensory movement features to eleven established BACs. The decisions form the basis for the hierarchical unweighted pair-group average cluster analysis which results in individual dendrograms. A comparison of the dendrograms via an invariance measure revealed similarities in the functional equivalence of biomechanical and sensory based movement constraints.

RESULTS
Biomechanical items show substantial differences; four of six are significantly different (e.g. Table 1). Consequently, in this test situation there is a trend towards an established difference of biomechanical items due to the influence of swim suits.

Table 1. Biomechanical parameters of the flip turn for both conditions.

<table>
<thead>
<tr>
<th>Test item</th>
<th>Regular swim suit</th>
<th>Full swim suit</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed into the wall (m/s)</td>
<td>1.68 (0.26)</td>
<td>1.91 (0.25)</td>
</tr>
<tr>
<td>speed of rotation (°/s)</td>
<td>291 (27.60)</td>
<td>284 (37.50)</td>
</tr>
<tr>
<td>speed push off (m/s)</td>
<td>2.48 (0.30)</td>
<td>2.58 (0.33)</td>
</tr>
<tr>
<td>time of leg extension (s)</td>
<td>0.286 (0.06)</td>
<td>0.294 (0.06)</td>
</tr>
<tr>
<td>drag coefficient (s)</td>
<td>2.85 (0.07)</td>
<td>2.70 (0.08)</td>
</tr>
<tr>
<td>Time total turn (s)</td>
<td>2.98 (0.32)</td>
<td>2.85 (0.25)</td>
</tr>
</tbody>
</table>

The sensory questionnaire reveals the following trends regarding substantial differences between the two test situations. In 15 of 23 cases the sensory movement features were judged to be different; three of 15 differences are statistically significant at the level of p<0.05 tested with paired t-test. These differences are considered reasonable evidence of the individual change in perception due to the influence of swim suits. The following keywords were ranked “more strongly recognized” while wearing full swim suits: estimate distance to the wall, keep equilibrium, vibration of muscles, tension in neck muscles, leg extension, pressure on stomach region, pressure on the soles, maximum change of body speed, buoyancy.

The following keywords were ranked “less recognized” while wearing full swim suits: gliding speed, rotational speed increases, look to the pool bottom, wave drag, drag effects start, keep speed.

The following keywords were not considered to be relevant: rushing of water, vibration of skin, renewed speed increase, drag effects release, lowest drag, pressure on shanks, pushing water mass, pressure on both side of legs, alternatively.

The study concerning the relation between the movement relevant BACs and biomechanical allocations, as well as the sensory movement features were done as grouped data, respectively, every group consisting of six swimmers. The mean group dendrogram of the BxB approach while wearing a regular swim suit differed significantly from the dendrogram while wearing a full swim suit.

The mean group dendrogram concerning the relation between BACs and sensory movement features via the BxF approach was done with the same swimmers. The dendrogram of the group wearing a regular swim suit differs significantly from the dendrogram of the group wearing a full swim suit. Moreover the comparison of the mental representation structures (dendrograms) based on sensory movement features and on biomechanical allocations are clearly similar as shown in Fig. 1. and Fig. 2.
Biomechanics and Medicine in Swimming XI

Figure 1. Grouped dendrogram of the flip turn in full suits according to BxB; marked gray areas represent cluster structures; numbers on the right are (Euclidian distances); the lower the distances between these BACs, the stronger the connection in the LTM. Keywords: 1 fix hands; 2 head on chest; 3 initial butterfly kick; 4 bending legs; 5 feet hit wall; 6 push-off; 7 streamline position; 8 gliding; 9 rotate hip/legs; 10 rotate stomach; 11 leg movement

Figure 2. Grouped dendrogram of the flip turn in full suits according to BxF. Keywords: 1 fix hands; 2 head on chest; 3 initial butterfly kick; 4 bending legs; 5 feet hit wall; 6 push-off; 7 streamline position; 8 gliding; 9 rotate hip/legs; 10 rotate stomach; 11 leg movement

DISCUSSION
This study is a first attempt to check experimentally via the cognitive representation of the flip turn technique how sensory effects influence the motor outcome under two different conditions: wearing a regular or a full swim suit. The different swim suits changed the representation of the sensory based effects, and thus influenced the postures of the flip-turn according to the conditions.

The particular mental representation was visualized by dendrograms (representing the cognitive representation) which give insight as to how Basic Action Concepts are related to each other. The dendrograms, when based on action allocations, are well structured and valid for experts executing such a movement. The dendrograms, when based on sensory movement features, show similar patterns. A comparison of the group dendrograms using a full swim suit revealed that sensory based representations are closely related to the biomechanical structure of the flip turn. A cross over comparison showed that different swim suits changed the sensory effects and thus influences the postures of the flip-turn. This change was manifested in the mental representations. This change leads to the question whether there is one mental representation in the long-term-memory that needs to be modified for different conditions, or if there are different ones for the different conditions.

The experiments revealed that sensory effects are strongly related to action keywords in the cognitive representation of a movement stored in LTM. This outcome is very promising for the work on technical aspects in swimming for elite swimmers. In striving for improvements related to the interaction of limb movement and water motion, the sensory movement features should be the training focus.

CONCLUSION
Any volitional or mentally controlled movement requires the encoding of the intended goal which principally acts as the trigger for subsequent cognitive processes establishing a mental model of the future on which mental control processes can depend. The transfer of the anticipated action into motor actions, executed at a mental representational level, is organized conceptually using cognitive compilation units, called BACs which finally serve to control actions effectively at lowest cognitive and energetic costs. Each BAC can be regarded as an invariant movement posture that is related to its sensory effects (Schack, 2004). All of the invariant movement postures need to be achieved to successfully perform the movement. Suppose that, whether or not a movement position is reached is decided by comparing actual perceptions to certain target perceptions. As soon as one BAC is accomplished sensory control is used to initiate the transition of the body to the next BAC. So the whole movement is under perceptive control. The structure of the movement and its effects and subsequently reached goals are stored together in the long-term-memory as a part of the motor repertoire.

Movements performed consciously or subconsciously change the position of the body in space and time and evoke a change in the environment. So the movement is initiated by the intention to evoke a certain change in the environment. Mainly subconsciously the needed movement is selected from the motor repertoire and adjusted to the situational influences. Thereby learned and automated movements can be accessed more easily.

Finally, after it has been shown that these keywords are of equivalent value, the research to find appropriate sensory based keywords for the various technical aspects in aquatic space is recommended.

REFERENCES

ACKNOWLEDGEMENTS
We thank the swimmers of the NZA for their participation, M. Truijens / Amsterdam for his support and C. Schütz / Bielefeld for technical advice.
The Role of Verbal Information about Sensory Experience from Movement Apparatus in the Process of Swimming Economization

Zatoń, K.

The University School of Physical Education in Wrocław, Wrocław, Poland

The way information is transferred and received in the process of learning motor swimming activities directly determines the effectiveness of the process. An effective way to improve the economization of the actions is through constant mastering of muscle tension regulation. This is only possible when a learner can receive information from the water environment, which affects his/her receptors in a conscious way. The aim of this study is to determine the impact of verbal information, which makes the learner aware of the kinaesthetic experience and which, in effect, decreases the physiological cost of work.

Key words: swimming, movement economization, word

INTRODUCTION

The main condition of learning in physical education, as in any form of education, is the work of stimuli on specialized reception organs (receptors). In these receptors alertness is generated which initiates nervous processes whose different degree of intensity reflects various intensity of the stimuli (Arnold, 1988; Cox et al., 1988). This initiates central nervous system, which is a precondition to further cognition stages, i.e. sensing, impression and perception (Sadowski et al., 2000). Sensing is the most basic and general impression related to stimulating receptors whose specifics are connected with a selected organ.

In the process of learning about moving one’s own body, which ensures an easy use of motor skills, certain information seems necessary; mainly the information coming from a teacher and related to qualitative categories of movement. Here, it seems as if the only effective form of information is a word, thanks to which a teacher may, together with a student, assess senses/sensory experience (e.g. muscle receptors). Making a student aware of those receptors seems only possible through the use of language.

Verbal information becomes especially valuable in a situation where a new set of movement solutions is introduced. Such sets may become a background for further success in sports, theatre or creative inspiration. Research to date suggests that teachers of physical education neglect the importance of verbal information in a teaching and learning process (Zatoń, 1988; Zatoń, 1999). They seem to consider that the basis for the creation of an image of a certain movement is through presentation. Verbal information serves only for the purposes of determining conditions for performing certain movements, as a means of warning against danger or for organizational purposes. However, as it has been proven in numerous studies dealing with the impact of verbal information on the effectiveness of learning, an effective educational process of learning movements should be generally based on a verbal message, not only in acquiring information, but also in maintaining balance of information (sensory stimulus) (Arnold, 1988; Strath et al., 2000; Zatoń, 1999). It is by means of verbal communication that information flow may be directed, its hierarchy and specifics determined. This refers particularly to those situations in which cognition takes place through stimulation of extero-receptors and inter-receptors in real time (Zatoń, 1999; Zatoń, 2002). The perception of senses coming from this may, and in some situations should, be predetermined by competent verbal information (Zatoń, 2002).

In the process of learning to swim, where the water environment requires a special pedagogical approach by a teacher, verbal information transferred by the teacher is of great significance. We are talking here about information provided by the teacher and reaching a student that explains the crucial ideas about perceived stimuli. This allows a learner to prepare for the information to come in such a way that it can be perceived effectively and selectively. The perception of senses from the movement apparatus during the process of learning and mastering swimming technique may be handled by way of proper verbal instruction. A conscious perception by the receptors translates into better understanding of one’s body position in space, and in effect a more optimal muscle tension. This may have an impact on faster and more economical learning of movement in water (Arnold, 1988; Fitts, 1996; Zatoń, 2002).

From the physiological view point in a situation where the mechanism of steering the movement is improved, and energy is gained (which occurs as a result of physical exercises) the physiological cost of work is decreased. This is commonly known as economization of effort. Physiological cost of work is – in turn – every instance where homeostasis is disturbed due to effort (Abbis et al., 2005; Bentley et al., 2007; Kubukeli et al., 2002).

The aim of this study is to determine the impact of verbal information on sensory experience from the movement apparatus (kinaesthetic) on economization of effort.

METHODS

48 students of the first year at the University School of Physical Education in Wrocław were the subjects in this study (24 men and 24 women). An average height of the men was 186 cm, their average mass was 87 kg. The average height of women was 168 cm and their average mass was 56 kg. The research was done in the second semester of the academic year 2007/2008 in the Laboratory of Movement in the Natural Environment at the Department of Swimming, which has certificate no 1374-d/1/2007 ISO 9001:2001. The research was done at the same time of day for all the subjects, in rooms with similar conditions (similar temperature and humidity). The students had been informed about the purpose of the experiment, its course and of what was expected from them.

To secure a homogenous group, those subjects who trained in sport professionally were eliminated.

The test group was divided randomly into three groups (control and two experimental). Before embarking on a proper experiment and before the groups were divided all the people that had been qualified to certain tests were subjected to a process of assessing their entry level ability to differentiate kinetically. This allowed us to determine the individual level of kinaesthetic differentiating.

The basic assumption of the experiment was to gauge the impact of verbal information provided by the researcher on the effort economization (physiological cost). This led to creating three groups: (1) control group – 16 people; (2) experimental group I – 16 people; (3) experimental group II – 16 people.

The first group performed movement tasks on the swim ergometer without verbal information that could have prepared them to perceive sensory experience from the movement apparatus. In experimental group I, while performing tasks on the ergometer, a verbal message was prepared, transferred and verified, so that the tested individuals could consciously prepare themselves for the information they were getting from the movement apparatus. This lasted as long as the cost of physiological effort could be observed as maintained at a constant low level.

The experimental group II, while performing identical tasks on the ergometer, received verbal information previously prepared and tested with the experimental group I.

The assessment of the level of kinaesthetic differentiation was performed using a method of muscle force movements repetition for elbow joints extenders in the lab of the Swimming Department. A detailed description of the method can be read in the publication by Zatoń and Klaworowcz (Zatoń et al., 2001).

The assessment of the effort economization (physiological cost) was performed with the use of the swim ergometer (Swim Ergometer – Weba Sport und Med. – Artikel CmbH) (Figure 1). It consisted of performing arms movements imitating crawl, in a given rhythm, with...
During the experiment the following were noted:

- movement frequency (Hz),
- force that the person subject to the test was using against the arms of the
  ergometer in each pull movement cycle (separately for each arm) (N),
- distance that the upper limbs covered in the movement cycle (m),
- pulse during the test and restitution time.

The purpose of the test was to observe differences occurring in the movement economization (physiological cost) of effort before and after performing the task, by measuring arm work frequency (5 min). The measure of the economization was the sum of heart rate frequency and rest time. It was assumed here that the change in the physiological cost is best shown by the sum of restitution frequency of heart rate according to the formula proposed by Klawowicz (1970). It was documented on many occasions that after effort the restitution effectiveness is important information on the level of tiredness (Abbis et al., 2005; Bentley et al., 2007; Cox et al., 1988; Kubukeli et al., 2002).

After the group was randomly selected (experimental group I) a verification of information contents was performed. Its purpose was to attain the test persons to a conscious perception of stimuli from the movement apparatus. The verification consisted in individual transmission of information while working on the swim ergometer. The researcher was looking for such verbal expressions that could directly translate to the decrease of effort. The experiment lasted as long as the tested person could receive an optimal version of the verbal information that would have a direct bearing on making his/her work more economical while performing the task on the swim ergometer (Zatoń et al., 2001).

The final version of the verbal information used in the proper experiment (experimental group II).

Lie on the bench so that you do not feel tension in any part of the body.

- Position your arms in a slightly bent position in elbow joints (10 – 15°).

During stroke movement slightly bend palms of hands (articulatio radiocarpea) (5 – 10°).

Perform the movement fluently (do not move abruptly). During the experiment concentrate on feeling steady pressure of the surface of "gauges" on the hand surface.

While feeling the pressure of "the gauges" on the palm receptors, try to regulate the pressure you are applying so that during the pull movement you will feel a maximum pressure, while performing the recovery movement, minimum pressure.

Table 1 shows the results of the experiment. The conclusion is that in the experimental group II, where the tested person working on the ergometer was provided with verbal information attuning the person to conscious perception of senses from the movement apparatus, statistically relevant differences were achieved. These differences demonstrated the effectiveness of after effort restitution (significantly better in the experimental group II).

### DISCUSSION

Calculation of correlation coefficients proves that there is a relationship between verbal information and movement economization (Bentley et al., 2007; Klawowicz, 1970; Kubukeli et al., 2002; Zatoń 2002). Therefore, the conclusion can be drawn that, the information expressed verbally on how to perform a movement, which should provide certain impressions, given by the researcher before, during and directly after the test, may make the tested person aware of the need to properly coordinate the action (Cox et al., 1988; Zatoń, 1999). Receptors in muscles, tendons and joints provide the central nervous system with the information on the movements and limb positions as well as positions of the other body parts (Arnold, 1988; Kubukeli et al., 2002; Sadowski et al., 2000). Ligaments transmitting these stimuli constitute a part of the so called movement neurons. Thanks to the information received from the nervous system, contractions of single muscles or muscle groups are co-ordinated, giving harmonious, subtle and effective movements. An intelligent teacher – possessing an inherent feature of eliminating excessive information – may create a hierarchy of verbal information, consciously drawing learner’s attention to selected fragments of this information. In the case of this experiment it was our intention to draw the reader’s attention to a conscious preparation on the part of the learner to perform selected elements of movements (proper hierarchization of movement actions and contraction) (Abbis et al., 2005; Arnold, 1988; Bentley et al., 2007; Cox et al., 1988; Sadowski et al., 2000). It can be stated that the major role in the movement optimization (economization) is played by verbal information that allows the learner to become aware of the essence of actions through self-control (Zatoń 1999; Zatoń et al., 1999; Zatoń et al., 2001; Zatoń 2002). We are aware, however, that this conclusion requires further research. Moving certain parts of the body in a proper way and in a certain sequence requires initiating thinking processes, i.e. perception, analysis, remembering, etc. as skeletal muscles are subject to conscious decisions. (Abbis et al., 2005; Arnold 1988; Cox et al., 1988; Fitts 1996; Strath et al., 2000; Zatoń et al., 2001).

### RESULTS

To determine the relationship between verbal information on perception from the movement apparatus and effort economization, basic statistical methods were used. Arithmetic average was measured, as well as standard deviation, Student’s t-test for dependent tests (within the same groups) and also a simple correlation between the tested features. Statistical significance was set at the confidence level, \( p \leq 0.05 \).

Table 1. Change in the amount of work (\( \Sigma \) work) and the sum of restitution heart pulse (\( \Sigma \) HR rest), in two groups (Control and Experimental I, II) before and after the end of the experiment and the significance of differences (t). \( (nK = 16, nE = 16) \).

<table>
<thead>
<tr>
<th>Feature</th>
<th>Control group test 1</th>
<th>Control group test 2</th>
<th>Experimental group I test 1</th>
<th>Experimental group I test 2</th>
<th>Experimental group II test 1</th>
<th>Experimental group II test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Sigma ) work</td>
<td>X 3089</td>
<td>KJ 248.12</td>
<td>X 3022</td>
<td>312.30</td>
<td>-0.11</td>
<td>3111</td>
</tr>
<tr>
<td>( \Sigma ) rest</td>
<td>X 202</td>
<td>rest 23.14</td>
<td>X 201</td>
<td>26.17</td>
<td>-0.02</td>
<td>212</td>
</tr>
</tbody>
</table>

Table 1 shows the results of the experiment. The conclusion is that in the experimental group II, where the tested person working on the ergometer was provided with verbal information attuning the person to conscious perception of senses from the movement apparatus, statistically relevant differences were achieved. These differences demonstrated the effectiveness of after effort restitution (significantly better in the experimental group II).
CONCLUSION
Self control, which is a conscious act of positioning limbs in relation to one another, to the body, head, and hence the structure of muscle tension and their sequence, may directly affect the decrease of the physiological cost of work. The results obtained show significant correlations between the verbal information used in the experiment and economy of movement.

REFERENCES
Chapter 6. Medicine and Water Safety
Crucial Findings from the 4W Model of Drowning for Practical and Teaching Applications

Avramidis, S. 1, 2, 3, McKenna, J., 1 Long, J., Butterfly, R., 1 Llewellyn, J.D. 4

1 Leeds Metropolitan University, UK
2 Hellenic Center for Disease Control and Prevention, Greece
3 Irish Lifesaving Foundation, Ireland
4 University of Cambridge, UK

This study aimed to suggest practical and teaching applications of the 4W model of drowning. A major literature review of quantitative research was undertaken to identify potential risk factors of drowning and qualitative content analysis was used to analyze publicly available drowning incident videos (n = 41, M = 345.0, SD = 2.8), and 34 individuals involved in drowning incidents were interviewed (30 males age 16–65 years, M = 28.4, SD = 11.3; 4 female age 19–65 years, M = 37.5, SD = 19.5). Results confirmed that test criteria such as a 100 m run–50 m swim–100 m run for open water and a 50 m run–20 m swim–50 m run for pool/water parks could be more useful for assessing speed combined with an ‘early approach’ to the victim than any currently in operation. The ‘early approach’ criterion would be established to test the ability of the lifeguard to be able to remain alert, to have good vision, to recognize the casualty’s instinctive drowning response, to initiate a rescue ignoring the bystander’s lack of response and to reassure the drowning victim. Drownings and their rescue interventions should be perceived as 3-dimensional problems.

Key words: lifesaving, lifeguarding, 4W model, drowning, water safety, teaching.

INTRODUCTION

Drowning is a serious social and health problem worldwide but most research focuses on epidemiologic and forensic aspects. Limited models and teaching theories have been suggested and implemented in the context of training, risk assessment, risk management and risk prevention of drowning (e.g. Griffiths, 2000; Pia, 1984; Connolly, 2004; Ellis & Associates, 1994). Because most of these theories and models were not scientifically established their effectiveness has been questioned (see Pia, 2007; DeRosa, 2008; Ellis and Associates & Poseidon Technologies, 2001).

Contrary to previous empirical published work, the 4W model on drowning was a research-based proposed theoretical framework aiming to offer an alternative way to understand the antecedents of drowning and assist teaching in the field of water safety (Avramidis, 2009). More precisely, this model suggested that when there is a human activity in, on, around, near or above an aquatic environment then a drowning incident may occur to whomever, wherever and under whatever circumstances (Avramidis et al, 2007). Later, using novel practices, research attempts were made to break the problem down into its basic building blocks (e.g. each one of the 4 W’s) in an effort to better describe who is more likely to be the rescuer (Avramidis et al, 2009a), who is more likely to be the casualty (Avramidis et al., 2009b), where (Avramidis et al., 2009c) and under what circumstances it is more likely a drowning incident may occur (Avramidis et al., 2009d). Therefore, the purpose of this study was to reassemble these basic building blocks into the 4W model and to suggest practical applications for enhancing teaching of drowning prevention and effective rescue.

METHOD

Consideration of debate about different paradigms (e.g. Morgan, 2007), their strengths and limitations (see Hoshmand, 2003; Johnson & Onwuegbuzie, 2004), led to the decision to undertake a mixed methods approach (Johnson & Onwuegbuzie, 2004) involving three studies. The first study was a review of quantitative studies, aiming to support the development of the theoretical framework of a 4W model. This model would contain all the potential variables present during a drowning incident (e.g. rescuer characteristics, casualty characteristics, place and circumstances of occurrence of a drowning incident). The second study based on observations of video recorded drowning rescues, aimed at assessing whether or not the variables found in the first study were present and whether other variables emerged. The third study was based on interviews, aiming to assess whether or not the variables found in the first study were present, and finding possible emerging variables, but also to give insights into questions that were left unanswered by the second study. Finally, the variables that were present in all three specific sets of data were synthesized to formulate a framework for drowning prevention. This methodological procedure aimed to achieve multiple triangulation. A more detailed explanation of the above will be given below.

STUDY 1

The first study was an extensive review of the literature on quantitative studies. It was important that this type of research came first in the current research design because the initial aim for the development of the drowning prevention framework was to identify as many variables related to drowning as possible. This could better be achieved by reviewing a broad range of quantitative studies that had already examined the drowning problem and located a number of related variables than by undertaking a quantitative or qualitative study with a limited sample. The terms ‘drown’, ‘aquatic emergency’, ‘risk factors’, ‘lifeguard’, ‘water safety’, ‘lifesaving’ and ‘rescue’ were used as key words in a search undertaken to identify literature with variables that might be involved in a drowning incident. The search used academic and professional aquatic safety textbooks that are routinely available in libraries, electronic databases typically available in academic libraries (e.g. Medline, Sport Discuss, Sport Discuss with Full Text, PsychINFO and PubMed) and search engines (e.g. Google and Yahoo) covering studies that assessed the epidemiology and risk factors of drowning. The available literature was limited to those available and published in Greek and English. Those qualitative data that were generated (i.e. variables related to drowning) were clustered in four pre-determined clusters namely ‘rescuer’, ‘casualty’, ‘place of drowning’ and ‘circumstances of drowning incident’. In an effort to identify as many variables related to drowning as possible, this review study included in the clusters not only variables that were well documented in the literature but also variables that appeared to be related to drowning in case studies. This ensured that possible contributing variables that might have been neglected from the water safety related literature would not be missed and would be given an equal chance of being included in the theoretical framework of the study.

STUDY 2

Data Sources: The exact data sources and procedures have been reported earlier (Avramidis, et al., 2007; 2009a; 2009b; 2009c; 2009d). A criterion-sampling method obtained drowning-incident videos (N = 41) that were freely available in the public domain. This method facilitated the identification of variables and their relationships that otherwise might not be available for fatal or non-fatal traumatic drownings. These visual narratives ranged in length from 30 to 720 s (M = 345.0, SD = 2.8).

Apparatus and Procedures: The authors observed the videos on standard equipment and software to perform appropriate qualitative analyses (QSR, 2002). To deal with the various disadvantages and bias, the objective and subjective audio and visual content of the video were observed without unsupported assumptions and editorial comments. The audio-visual content was transcribed twice within a period of three months. This text was inserted into the computer software NVivo (version 2002) for content analysis. A number of codes were identified within the text. Finally, frequencies were measured.
STUDY 3
Participants: A combination of convenience and snowball sampling, located participants who were water safety or aquatic professionals (e.g., lifeguards, lifesavers, scuba divers, and athletes of aquatic sports \(N=34\)) who could describe a drowning episode (Table 1).

| Gender | 30 males (age 16–65 years, \(M = 28.4, \text{SD} = 11.3\))  
|        | 4 female (age 19–65 years, \(M = 37.5, \text{SD} = 19.5\)) |
| Nationality | Greece (\(n = 25, 71.4\%\))  
|            | United Kingdom (\(n = 2, 5.7\%\))  
|            | United States (\(n = 1, 2.8\%\))  
|            | Cyprus (\(n = 6, 17.1\%\)) |
| Place of Reported Drowning | Sea (above the water surface) (\(n = 23, 67.6\%\))  
|            | Sea (under the surface of the water surface) (\(n = 5, 14.7\%\))  
|            | Lake (\(n = 2, 5.9\%\))  
|            | Swimming pool or water park (\(n = 4, 11.8\%\)) |

Apparatus and Procedures: The same procedure as in the previous study (that examined observation of video recorded rescues) and past published work was followed (Avramidis et al., 2007; 2009a; 2009b; 2009c; 2009d). Anonymity and confidentiality were maintained. The participants received and read participant information sheet and, after having any questions about their involvement answered to their satisfaction, signed an informed consent form. The semi-structured interview schedule included open-ended questions. The interview was transcribed and inserted into the computer software NVIVO for content analysis.

RESULTS AND DISCUSSION

The aim of the present mixed methods research approach was to suggest practical applications for drowning prevention and demonstrate the efficacy of the proposed 4W model. A number of crucial findings therefore need to be discussed.

Distance from Safety and the 3-Dimensions of Drowning and Rescue Intervention: The video and interview analyses showed that the distance from safety was a component of each drowning incident (Avramidis, 2009). In particular, it was shown that the distance of drowning episodes from safety ranged from 1–9 m up to many miles. Considering that distance from safety is one of the components that affected the speed of rescue and also that speed equals time, then there was a need to locate spatially the activity prior to the incident and the location of drowning to understand its antecedents. Consequently, depicting a drowning victim in a geometric model at the centre of 3-dimensional space yielded crucial findings. Drowning was the outcome not only of engagement in aquatic activities as swimming, boating, sailing etc. or depth (e.g. knowledge of marine life dangers, underwater currents, water temperature etc.). Therefore, this stressed the need for further education from the rescuer's point of view. Additionally or purposely inflicted). Second, it stressed the need, from an educational point of view, for better public awareness regarding water safety prevention in people who engage not only in aquatic activities but also in non-aquatics in, on or around the water, for them to know how to swim and be able to survive in an aquatic emergency.

Third, it showed that the 400 m swim for open water rescue and the 50 m swim for pool/water park rescue on their own were not adequate teaching and test requirements to ensure a speedy approach because they assessed speed in only one dimension. Instead, test criteria such as a 100 m run–50 m swim–100 m run for open water and a 50 m run–20 m swim–50 m run for pool/water parks could be more useful for assessing speed in relation to distance.

Finally, the presence of each dimension and the number of metres between the rescuer and the casualty of each of those dimensions posed an additional number of obstacles that had to be overcome. For example, a lifeguard who attempted a 1-dimensional rescue at a certain distance from safety was concerned with fewer variables (e.g. distance from safety, weather and environmental conditions etc.) than a rescuer who attempted a 3-dimensional rescue who was concerned with all variables related to width (e.g. run, likelihood of getting injured), length (e.g. swim, need to fuel and operate a power boat or a helicopter etc.) and possibly height (e.g. knowledge of handling a specialized rescue, concern about weather conditions etc.) or depth (e.g. knowledge about marine life dangers, underwater currents, water temperature etc.). Therefore, this stressed the need for further education from the rescuer's point of view.

Early Approach: A crucial finding of this research was that when approaching the drowning victim, an early approach was required by amateur and professional rescuers in the video and interview samples by the distance between the location of drowning in inland water from the land in such activities as walking or driving in flooded areas and frozen lakes etc. In other words, this showed that lifeguards, professional rescuers and amateur lifesavers had to respond to drowning episodes whose starting point was one of the previously described dimensions at various distances from safety. Therefore, people became drowning victims regardless of whether or not the distance of their undertaken activity was far from the water.

A rescue intervention in the videos and interviews was a 3-dimensional task. Rescues rarely occurred exactly in front of the eyes of the rescuer on a perpendicular plane to allow a 1-dimensional intervention. For example, the interviewee lifeguards from Greece who supervised 600 m and were positioned in the middle of a beach, had to run across the beach a number of metres (e.g. dimension of width), attempt a swimming approach from the shortest distance (e.g. dimension of length) and possibly continue with an underwater search for the unconscious submerged drowning victim (e.g. dimension of depth). Similarly, in other rescues from the video analysis a rescuer had to run to the place where the helicopter was parked (e.g. dimension of width), fly to the place where the victim was drowning (e.g. dimension of length) and attempt a rescue which required the rescue swimmer jumping into the water and the eventual lift, together with the victim, into the helicopter (e.g. dimension of height). This showed that lifeguards, professional rescuers and amateur lifesavers had to respond to drowning episodes covering a distance from safety to the place of the event in more than one dimension.

All these points suggested that perceiving drowning and the consequent attempted rescue as a 3-dimensional problem and task respectively had a number of implications. First, it revealed a number of ‘hidden’ drowning incidents that contemporary injury epidemiology would classify under different codes, underestimating the burden of drowning and therefore the magnitude of the problem, with negative consequences in decision making to fund research and education in terms of prevention, rescue and treatment (e.g. E830, accident to watercraft causing submersion; E832, other accidental submersion or drowning in water transport accident; E984, submersion [drowning] undetermined whether accidentally or purposely inflicted). Second, it stressed the need, from an educational point of view, for better public awareness regarding water safety prevention in people who engage not only in aquatic activities but also in non-aquatics in, on or around the water, for them to know how to swim and be able to survive in an aquatic emergency.
CONCLUSIONS

A number of conclusions arose from the synthesis of the present 3 studies. First, teaching prerequisites and test criteria like a 100 m run–50 m swim–100 m run for open water and a 50 m run–20 m swim–50 m run for pool/water park lifeguarding could be useful for assessing speed combined with an ‘early approach’ to the victim. Second, the ‘early approach’ teaching and assessment criteria establish importance of the ability of the lifeguard to be able to remain alert, to have good vision, to recognize the casualty’s instinctive drowning response, to initiate a rescue ignoring the bystander’s lack of response and to reassure the drowning victim. Finally, drowning incidents and their rescue interventions should be perceived as 3-dimensional issues.

REFERENCES


QSR. (2002). NVIVO, Getting Started in NVIVO. Australia: QSR International Pty Ltd.
Swimming, Cycling, Running and Cardiovascular Health

Bagheri, A.B. 1, Mohebdi, H.D. 2, Azizi, M.H. 3, Saiari, A.R. 4
1Islamic Azad University-Dezful Branch, Dezful, Iran
2University of Guilan, Rasht, Iran
3Islamic Azad University-Abadan Branch, Abadan, Iran

A number of epidemiological studies have proved the benefits of regular physical activity for the prevention of CHD. Exercise recommendations for health can be obtained from extrapolation between different modes of exercise. Forty non-athlete male youth participated in this study for the comparative effects of swimming, cycling and running on lipid and lipoproteins serum. In this study, after aerobic training, HDL-c increased and LDL-c decreased, so TC and TG decreased. The findings suggest that moderate training performed over many weeks induces positive changes in the plasma lipid and lipoproteins concentration in youth. However, there were differences between the three groups. Swimming, running and cycling are positive for health, although this study suggested that they have different effects.

Key words: swimming, cycling, running, aerobic training, TC, TG, LDL-c, HDL-c

INTRODUCTION
Cardiovascular diseases (CVD) are also reported to be the leading cause of death in the eastern Mediterranean region including Iran. Epidemiological studies have shown that a sedentary life and obesity are related to coronary heart disease (CHD) (Andersen et al., 1995). In numerous studies, inverse associations have been demonstrated between physical activity, obesity and CHD (Daniel J. G. 2008. Kline et al., 1987. King et al., 1995). A number of epidemiological studies have proved the benefits of regular physical activity for the prevention of CHD. Despite the fact that exercise is crucial in weight management, the obese are found to have reduced exercise tolerance compared with the non-obese and are, in fact, less active. Fat is the major source of energy during low-intensity exercise, and as the intensity increases, the proportional contribution of fat decreases. Nonetheless, at 75-80% of VO2max, total fat oxidation is markedly above the resting value because the proportional contribution of fat oxidation is not great, the total rate of energy expenditure is high. Plasma fatty acids are the major source of energy during mild to moderate energy expenditure. Exercise recommendations for health can be obtained from extrapolation between different modes of exercise.

METHODS
Subjects: Forty non-athlete men (Age 22.56 ± 2.77 yr) with overweight (BMI >25 kg·m-2) participated in this study. Subjects were made fully aware of the risks, benefits and stresses of the study and were given both verbal and written instructions outlining the experimental procedure, and their informed consent was obtained before screening. The personal and medical information of the participants was obtained, as well as previous exercise history by questionnaire. A pre-participatory exercise screening questionnaire [Physical Activity Readiness questionnaire (PARQ)] was administered (Chisholm et al., 1975). All participants were asymptomatic and were not taking any form of medication known to affect the lipoprotein profile. Before the training program (baseline), according to the National Cholesterol Education Program (NCEP, 26) classification of risk, no participants had "borderline" or "desirable" concentrations of either TC and LDL-C. These youth were all classified as having "desirable" concentrations of TC and LDL-C at baseline. Subjects were divided into four groups randomly; that included ten persons each. Three groups were assigned training regimens (swimming, running, and cycling), and completed the exercise training program. Ten subjects served as controls.

Measurements: Body weight (BW) was measured through calibrated clinical scale and height was measured through stadiometer while the participants wearing light clothing with no shoes. Body Mass Index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg·m-2). Five ml of venous blood sample were collected after a 12-14 hours fast into vacationer tubes without anticoagulant in pre-test and post test. Blood was allowed to clot at room temperature for 30 min before being centrifuged. Serum and red blood cells were separated by centrifuge at 1500g for 20 min. serum was transferred and stored at -80º for analysis of lipids and lipoproteins. Total cholesterol (TC) was measured by the CHOD-PAP method. TG by the GPO-PAP method, high density cholesterol (HDL) was determined after separation with phosphotungstic acid and magnesium chloride, all using established kit methods from Boehringer (Mannheim, Germany). Low density lipoproteins (LDL) was then estimated by using the Friedewald equation (Friedewald et al., 1972).

Swimming Training: Ten non-athlete male volunteers used swimming training three times per week (t/wk) consecutively for 16 weeks. Technique training (crawl) was provided to the subjects before starting. The swimming training program consisted of submaximal crawl 30 min pr day (min/d) (5 min activity and 2 min rest), 2d/wk with 50 – 60 percentage of each subject’s predicted maximal heart rate (max HR) intensity in first and second month. Throughout the remainder of the month, subjects trained at 30 min/d (5 min activity and 1 min rest), 2d/ wk, approximately 70 – 80 percentage of maxHR. During this study, the subjects conducted to warm-up and cool-down (static stretching and low intensity exercise).

Running Training: Ten non-athlete subjects performed running exercise three t/wk during 16 weeks. They trained at 30 min/d (5 min activity and 2 min rest), 2d/wk with 50 –60 percentage of each subject’s max HR intensity in first and second week. Almost all subjects were working at approximately 70 – 80 percentage of maxHR in throughout the remainder of the weeks.

Cycling Training: Ten non-athlete male ended cycling (ergometer) exercise three t/wk consecutively for 16 weeks. Subjects trained at 30 min/d (5 min activity and 2 min rest), 2d/wk with 50 –60 percentage of each subject’s predicted max HR intensity in first and second week. Almost all subjects were working at approximately 70 – 80 percentage of maxHR in throughout the remainder of the weeks.

Statistical Analysis: Before hypothesis testing, data were assessed for normality of distribution and homogeneity of variance. SPSS (V 15) and Microsoft office Excel (V 2007) was utilized for statistical analysis and graphic presentation. Main effects of training modality and time (pre and post-exercise), were assessed using One-Way Analysis of Variance. Statistical significance was conferred at P ≤ 0.05. Tukey test was used for post hoc comparisons, when main effects were detected.

RESULTS
After 16 week of swimming, cycling and running exercise, there were differences between experimental groups and control for TC (P ≤ 0.05) (Figure 1). (Control Group = 155.78 ± 35.3 vs. 157.35 ± 35.4, Swimming Group (SG) = 155.76 ± 33 vs. 163.41 ± 35.9, Cycling Group (CG) = 154.93 ± 36 vs. 140.03 ± 21.8; Running Group (RG) = 156.34 ± 34.7 vs. 139.25 ± 35.8). Total Cholesterol in three groups decreased; SG: 12.42%, CG: 9.61%, RG: 10.93%. Comparison with Tukey test showed that no significant differences between Control Group and CG (p = 0.530) so RG (p= 0.317); but there were significant differences between control group and SG (p = 0.012).
There were differences between the experimental group and the control group for Triglyceride (P ≤ 0.05) (Figure 2). (Control group = 146.1 ± 29.9 vs. 144.4 ± 2.1; SG = 143.4 ± 26 vs. 126.3 ± 14.6; CG = 142.7 ± 24 vs. 130 ± 38.0; RG= 145.1 ± 28.3 vs. 130.5 ± 41.4). TG in three groups decreased; SG: 11.92%, CG: 8.89%, RG: 10.06%. Comparison with Tukey test showed that no significant differences between Control Group and CG (p = 0.380) so RG (p = 0.221); but there were differences between control group and SG (p = 0.009).

There were differences between the experimental group and the control group for Triglyceride (P ≤ 0.05) (Figure 2). (Control group = 146.1 ± 29.9 vs. 144.4 ± 2.1; SG = 143.4 ± 26 vs. 126.3 ± 14.6; CG = 142.7 ± 24 vs. 130 ± 38.0; RG= 145.1 ± 28.3 vs. 130.5 ± 41.4). TG in three groups decreased; SG: 11.92%, CG: 8.89%, RG: 10.06%. Comparison with Tukey test showed that no significant differences between Control Group and CG (p = 0.380) so RG (p = 0.221); but there were differences between control group and SG (p = 0.009).

Following 16 week of swimming, cycling and running, there were significant differences between the experimental groups and control group for HDL-c (P ≤ 0.05) (Figure 4). (Control Group: = 40.2 ± 17.8 vs. 39.98 ± 15.4; SG = 40.33 ± 7.9 vs. 50.01±8.4; CG = 40.46 ± 3.5 vs. 48.40 ± 3.2; RG = 42.84 ± 6.1 vs. 51.14 ± 9.6). HDL-c increased: SG: 24.00%, CG: 19.62%, RG: 19.37%). Comparison with Tukey test showed that no significant differences between Control Group and CG (p = 0.191); but in comparison with control group there were no differences.

REFERENCES


### Analysis of Aerobic/Aerobic Performance in Functionally Disabled Swimmers: Low Classes vs High Classes

**De Aymerich, J.¹, Benavent, J.², Tella, V.³, Colón, J.C.³, González, L.M.², García-Massó, X.³, Madera, J.²**

¹Universidad País Vasco, Vitoria, España
²Universidad de Valencia, Valencia, España

The main aim of this study was to examine whether there are differences in the LA accumulation in disabled swimmers belonging to the lower classes, higher classes and those without functional disability. The sample was made up of 38 swimmers, 10 disabled swimmers from classes 1 to 5 (G1), 9 swimmers from classes 6 to 10 (G2) and 10 swimmers without functional disability (G3). The swimmers performed two bouts of swimming: one anaerobic and the other aerobic-anaerobic. The ANOVA showed significant differences between the groups (p<0.005). Finally, in anaerobic and aerobic-anaerobic intensities, the swimmers of the lower classes have a lower LA accumulation than the swimmers from higher classes and the swimmers without any functional impairment.

### Keywords: Swimming, lactate, disabled, aerobic, anaerobic

**INTRODUCTION**

The measurement of lactate concentration (LA) in blood has been used as an indicator of strength level and of the intervention of the anaerobic metabolism since the 80s (Hellwing et al., 1988) and this is a common procedure in order to evaluate athletes response to endurance exercise (Foster et al., 1999).

The lack of research on the performance of this variable among disabled swimmers can be a result of the difficulty in establishing protocols, the large number of different classes of disability or the small number of athletes (Chin et al., 2001; De Aymerich, 2007).

Among the studies done with swimmers with disability on anaerobic threshold Denadai (2002), studied the LA concentration according to their performance and disability (Esau et al., 2006) and the lactate concentration in relation to aerobic and anaerobic exercises (Pelayo et al., 1995).

When competitive disabled swimming was not so widespread and the participation of these athletes was at a lower level than today, their training level showed many deficiencies. These reasons may be the cause of the contradictory results that were obtained by some authors (Telford et al., 1988), given the heterogeneity of the groups and their low level of performance.

Our motivation for the present study has been the challenge given to a selected group of swimmers with functional disability to take part in The Paralympic Games (Beijing 2008). Their training is very similar to elite swimmers in terms of method, dedication and intensity, which allows us to examine whether some of the metabolic responses produced by the stimuli used when training are similar to the ones used with swimmers without disability. Given the results obtained, adapting their training to a more specific basis depending on the functional characteristics of each group, is a challenge.

This study has also been motivated by the revision of the sport situation of the disabled swimmer. The recommendations given by Garathena et al. (2006), to continue reviewing the appropriate protocols for disabled swimmers, encouraged the studying of the different physiological responses with different functional groups of disabled swimmers. Consequently, the aim of his study was to examine whether there are differences in the LA accumulation in disabled swimmers belonging to low classes (groups), high classes (groups) and without functional disability in maximum anaerobic and aerobic-anaerobic intensities.
METHODS
The sample consisted of 29 swimmers, 10 of them were disabled swimmers of functional classes 1 to 5 (G1), 9 disabled swimmers of functional classes 6 to 10 (G2) and 10 able swimmers (G3). The descriptive average values of the swimmers characteristics were (mean±standard error of the mean) height 163.8±6.17 cm, weight 56.83±2.39 kg and age 27±2.04 years for G1; 170.67±5.39 cm, 62.72±5.67 kg and 27.44±3.5 years for G2; and 174.72±2.43 cm, 66.87±2.66 kg and 17.5±0.8 years for G3. Table 1 presents information about the disability of the G1 and G2 swimmers.

Table 1. Type of disability, and number of subjects affected by each disability of the Groups 1 and 2

<table>
<thead>
<tr>
<th>Disability</th>
<th>Group 1 (n=10)</th>
<th>Group 2 (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focamelia</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Arthrogryposis</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Paraplegia</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Amputee</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cerebral palsy</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Brachial plexus lesion</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Perthes</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Spinal cord disorder</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Muscular atrophy</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

All the swimmers of G1 and G2 belonged to the national swimming team that competed at the Paralympic Games in Beijing. G3 group subjects were national level swimmers without disability from different clubs. The subjects signed an informed consent form before starting the protocol, this being checked by the Research Commission of the Department of Physical Education and Sports at the University of Valencia (Spain). All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its later amendment in 2008.

With the aim of verifying whether the lactate accumulation after a maximum anaerobic effort (R1) and another aerobic-anaerobic effort (R2) differ between disabled swimmers (high and low classes) and non disabled swimmers, each subject performed one set of each test (R1 and R2). The subjects did the tests using their competition stroke. Table 2 shows the number of swimmers for each stroke. The subjects did two series. The objectives of these series were to reach the maximum LA concentration after an anaerobic effort (R1) and an aerobic-anaerobic effort (R2). After finishing each test, LA level was registered at five points (i.e. 1, 3, 5, 7 and 9 minutes after the test). Before test R1, resting LA was taken (mean±SEM) (G1: 1.38±0.09, G2: 1.48±0.10, G3: 1.41±0.11). Although resting LA value before R2 was not registered, R2 was not started until the LA level was similar to resting LA before R1. One minute after finishing each series, a blood sample for LA level, was taken every two minutes till the highest LA peak was reached (i.e. 1, 3, 5, 7, ... minutes). The highest lactate peak was the one used for later analysis.

Table 2. Number of subjects that used each swimming stroke in the three groups.

<table>
<thead>
<tr>
<th>Stroke</th>
<th>Group 1 (n=10)</th>
<th>Group 2 (n=9)</th>
<th>Group 3 (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freestyle</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Butterfly</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Backstroke</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Breaststroke</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

All the subjects did the R1 series first at the maximum intensity. After a 30 minute rest, they did R2 series to the maximum intensity. R1 distance for each subject was the one that allowed (depending on the swimmer’s disability and or performance level) to complete as many laps (i.e. 25 meters) each as near 60 seconds as possible. To calculate the swimming distance of R2, approximately 240 seconds was the length to complete. Average time (mean±standard error of the mean, SEM) for R1 was 73.23±3.15 seconds and for R2 was 224.48±11.3 seconds, without differences between groups.

Lactate level for each subject was registered after the test. 5 µl of capillary blood was examined with the lactate examiner Lactate- Pro. Statistical analysis was carried out using SPSS software version 17 (SPSS inc., Chicago, IL, USA). It was checked that all the variables complied with the assumption of normality (K-S normality test) before analyzing the data. Standard statistical methods were used to obtain the mean as a measurement of the central trend and the standard error of the mean (SEM) as a measurement of dispersion. A mixed model 3(group) x 2(test) ANOVA was performed to discover differences between the exercises and groups. For those variables where the ANOVA showed significant differences, post hoc analysis were requested using Bonferroni adjustment to determine between which exercises these differences appeared. The level of statistical significance was set at p<0.05.

RESULTS
The experimental values of the LA levels of the three groups in each condition appear in the Table 3.

Table 3. Blood lactate levels differences between groups and conditions.

<table>
<thead>
<tr>
<th>Group</th>
<th>R1 (mmol/LA)</th>
<th>R2 (mmol/LA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (n=10)</td>
<td>9.52 (0.81) *†</td>
<td>11.93 (0.63)</td>
</tr>
<tr>
<td>Group 2 (n=9)</td>
<td>11.17 (0.43)</td>
<td>10.7 (0.47)</td>
</tr>
<tr>
<td>Group 3 (n=10)</td>
<td>7.39 (0.8)</td>
<td>9.78 (0.45)</td>
</tr>
</tbody>
</table>

Data are expressed as mean (standard error of the mean). * Significant differences (p<0.05) in relation to group 2. † Significant differences (p<0.05) in relation to group 3.

The results show that there was a main effect of group on the blood lactate levels (F2,26=7.88, p=0.002). Post hoc analysis showed that group 1 obtained levels of lactate smaller than the levels of the group 2 and 3 (p<0.05) on both tests, but no differences existed between groups 2 and 3 (p>0.05) (see table 3). Also, there was a main effect of the condition (i.e., type of effort) on the blood lactate levels (F1,26=31.4, p<0.001). Pair wise comparisons revealed that the blood lactate levels were higher in anaerobic test than in the aerobic-anaerobic test in the three groups (p<0.05) (see Table 3). However the ANOVA did not show an interaction effect.

DISCUSSION
The difficulty in selecting homogenous groups from within groups of disabled swimmers is the reason why the groups are made up of both sexes. On verifying the composition of groups of previous studies (Denadai et al., 2002; Garatachea et al., 2006), it can be seen that this consideration has been taken into account. The homogeneity demonstrated in the composition of the groups could be justified by the negligible influence of gender on the maximum concentration of lactate in maximum efforts (Telford et al., 1988; Arvonitou, 1996). In both studies, the swimmers were in the competitive period and no significant differences were found in the LA peak between men and women.

One aspect relevant to our study has been the separation of the disabled swimmers into two groups. In these athletes, the variety of disabilities is wide, even when analyzing a single group of functional classification. The reason why the swimmers did both repetitions in their best style is justified by requirement to carry out the protocol at maximum intensity and thereby guarantee their maximum lactate concentration. Arvonitou (1996) established that, for men, 200 freestyle and 200 individual medley and, for women, 200 freestyle and 400 individual medley are the events with the greatest LA accumulation. Although in all three groups there are swimmers who did the series in different strokes, 80% of the G1 swimmers did the test in front crawl, while in the other two groups between 30% and 60% swam freestyle. These differences may impose a limitation on the obtained results.

The distance in R2 was selected for each swimmer with the objective of achieving a maximum effort over a period of approximately four
minutes, thereby determining the maximum lactic acid concentration at an intensity whose main source of energy was supplied by the anaerobic lactate as well as the aerobic system (Zamparo et al., 2000; Capelli et al., 1998). In this way, the swimmers did the R2 over a distance of 150 to 200 meters, or 300 to 400 meters, according to their swimming speed.

In the same way, the duration of 60 seconds was selected for every swimmer in R1 to swim at maximum effort and so determine the maximum LA concentration at an intensity whose main source was supplied by the anaerobic lactate system (Zamparo et al., 2000; Capelli et al., 1998). Thus the swimmers carried out R1 over a distance of 50 to 100 meters according to their swimming speed.

This decision meant that there were no significant differences (p<0.05) in the swimming time between groups in R2 (G1=212.82 ± 57.96; G2=248.02 ± 66.60; G3= 208.95 ± 67.33) y en R1 (G1=76.76 ± 16.61; G2=75.90 ± 21.02; G3= 67.33 ± 9.02).

Roi & Cerriza (1992) studied the difference between disabled and non-disabled swimmers over the same distance for both groups (50 meters). The results obtained do not account for the fact that disabled swimmers required a swimming time of approximately 129% of the non disabled (26.66” vs 61.29”). One of the contributions of our study is to show the necessity of equating the swimming times and intensity, as opposed to selecting the same distance, when comparing the performance between swimmers with and without disabilities.

The swimmers with disabilities showed similar values (G2) or lower (G1) to the swimmers without disability (G3). However, Pelayo et al. (1995) present higher LA concentration values in swimmers with disabilities than the swimmers without disabilities on intensities related to the maximum aerobic speed (similar to our R2), evidencing the difference in training programs for the swimmers with and without disabilities.

If the LA accumulation depends on the musculature engaged during the effort (Ohkuma & Itoh, 1992), it seems reasonable to think that the characteristics of the different disabilities of the swimmers from lower classes, would limit the neuromuscular activation relative to the swimmers from higher classes and swimmers without disabilities. For example G1 was formed by 4 cerebral palsy and 3 paraplegic swimmers.

Another aspect to analyze is the differences in LA between R1 and R2 in the different groups. Although the results obtained do not show differences between repetitions, the analysis for each swimmer shows whether the maximum LA concentration can be found in R1 or in R2 (Table 4).

**Table 4. Individual blood lactate levels for groups and conditions.**

<table>
<thead>
<tr>
<th>Group 1 (n=10)</th>
<th>Group 2 (n=9)</th>
<th>Group 3 (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R1 vs R2 (mmol/LA)</strong></td>
<td><strong>R1 vs R2 (mmol/LA)</strong></td>
<td><strong>R1 vs R2 (mmol/LA)</strong></td>
</tr>
<tr>
<td>7.3</td>
<td>6.8</td>
<td>11.3</td>
</tr>
<tr>
<td>8.9</td>
<td>6.9</td>
<td>8.9</td>
</tr>
<tr>
<td>11</td>
<td>7.6</td>
<td>11.4</td>
</tr>
<tr>
<td>8.6</td>
<td>5.7</td>
<td>14.2</td>
</tr>
<tr>
<td>12</td>
<td>9.2</td>
<td>11.7</td>
</tr>
<tr>
<td>12</td>
<td>7</td>
<td>10.4</td>
</tr>
<tr>
<td>9</td>
<td>9.7</td>
<td>10.8</td>
</tr>
<tr>
<td>6.4</td>
<td>3.4</td>
<td>13.6</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
<td>9.6</td>
</tr>
<tr>
<td>6.4</td>
<td>5.2</td>
<td>-</td>
</tr>
</tbody>
</table>

As Table 4 shows, four swimmers obtained similar values between R1 and R2 (±0.5 mmol/LA), three swimmers obtained greater values in R2 (±0.5 mmol/LA), while the rest of the swimmers obtained greater values in R1 (±0.5 mmol/LA).

The LA concentration in aerobic-anaerobic intensities can vary as a function of the training carried out on the aerobic or anaerobic system, as indicated in the latest scientific results (Kirsten et al., 2008). Thus the concentration of LA in R1 with respect to R2 could be due to the physiological adaptations produced by the type of training; whether aerobic or anaerobic.

**CONCLUSION**

To conclude, at anaerobic and aerobic-anaerobic intensities, the swimmers of the lower classes have a lower LA accumulation than the swimmers from higher classes and the swimmers without any functional impairment. However, the swimmers from the higher classes have a similar LA accumulation to those swimmers without functional disability.

**REFERENCES**


Athletic Rehabilitation of a Platform Diver for Return to Competition after a Shoulder Dislocation

Fujinawa, O.1,2, Kondo, Y.1, Tachikawa, K.3,4, Jigami, H.1,5, Hirose, K.6, Matsunaga, H.3

1Medical Science Committee of Niigata Swimming Federation, Nagasaki, Japan
2Saitama Prefectural University, Koshigaya, Japan
3Yayukkenomura Hospital, Nagasaki, Japan
4Niigata University of Health and Welfare, Niigata, Japan
5Himeji Dokkyo University, Himeji, Japan

A high-school male diver was diagnosed with tendinitis of the left supraspinatus tendon secondary to shoulder dislocation during the water-entry stage of a 10-m dive. Land-based athletic rehabilitation consisting of 15 sessions was initiated at a hospital on the 5th day after the injury. After treatment with anti-inflammatory medication and immobilization by using a chest band, the patient performed stabilizing exercise of the glenohumeral joint and scapula abduction-adduction exercises from the 13th to the 22nd day. Aquatic rehabilitation (total, 6 times) was started on the 17th day; joint mobilization of the glenohumeral joint and mobilization with movements and motor control exercises were applied until just before competition. He started diving practice on the 21st day; then, he returned to the National Sports Festival competition and won the 2nd prize for the 10-m platform dive on the 26th day after injury.

Key words: mobilization with movement, joint mobilization, PNF, impingement, motor learning

INTRODUCTION
Diving-related injuries among children and adolescents younger than 20 years were comprehensively examined, and the research showed that the percentage of upper-extremity injuries was 9.5% (Day et al., 2008). According to their report, the frequency of diving-related extremity injuries was relatively low. In this study, we describe the treatment and rehabilitation protocol for a high-school diver with an injury to the left supraspinatus tendon secondary to shoulder dislocation during the water-entry stage of a 10-m dive. He started athletic rehabilitation on day 5 after the injury, and he tried to dive on the 21st day; then, he returned to the National Sports Festival in Japan and won the 2nd prize for 10-m platform diving on the 26th day after injury. The objective of this case study is to retrospectively analyze the rehabilitation program and to suggest effective physical therapy (PT) procedures with regard to the biomechanical aspect.

METHODS
The patient’s medical records, including magnetic resonance imaging (MRI) scans, were evaluated, and the PT records for hospital and poolside rehabilitation were retrospectively analyzed with regard to the biomechanical, anatomical, and kinesiological aspects. This study program was approved by the Saitama Prefectural University Ethical Committee.

RESULTS
History. The male patient, who was 17 years of age, experienced shoulder dislocation during diving practice for the Inter-High School Championships held outside his native city. He dislocated his left shoulder due to abduction of the arm during entry into the water. When a coach raised him from a supine to a sitting position to apply a sling at pool side, the dislocated shoulder was spontaneously reduced. He was admitted for emergency care to a local hospital because of joint swelling and severe pain. After the championship, he visited the orthopaedic department of a hospital in his native city and commenced land-based rehabilitation (Table 1).

Diagnosis and Medication. He was diagnosed with supraspinatus tendinitis, and MRI indicated swelling of the supraspinatus tendon and glenohumeral hydrarthrosis (fig. 1). Anti-inflammatory medication and immobilization by a chest band were prescribed.

Land-based rehabilitation at a hospital commenced on the 5th day after injury and was completed on the 22nd day (15 visits total). During the immobilization period (from the 5th to the 12th day), PT programs consisted of the sound side and general conditioning exercises. From the 13th to the 22nd day, the PT programs introduced stabilization exercises of the left glenohumeral joint using isometric rotator cuff exercises and scapula abduction-adduction exercises. Concentric and eccentric rotator cuff exercises of the glenohumeral joint using a rubber band were also used. The objectives of the scapula abduction-adduction exercises were to gain optimal scapular mobility and stability for normal scapulo-humeral rhythm and to prevent glenohumeral joint dysfunctions, such as abnormal stresses to the anterior capsular structures, increased possibility of rotator cuff compression, and decreased performance. Isometric, concentric, and eccentric rotator cuff exercises were applied to keep the optimal position of the glenohumeral joint and to improve adequate balance of internal and external rotator muscle strength (Niederbracht et al., 2008).

Table 1. Process of Athletic Rehabilitation

<table>
<thead>
<tr>
<th>Day*</th>
<th>Situations / Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>12th</td>
<td>Land-based rehabilitation at a hospital</td>
</tr>
<tr>
<td>13th</td>
<td>Detachment of the immobile brace and exercises of the affected arm</td>
</tr>
<tr>
<td>15th</td>
<td>Swimming team training</td>
</tr>
<tr>
<td>17th</td>
<td>Aquatic rehabilitation at pool side</td>
</tr>
<tr>
<td>18th</td>
<td>2nd Aquatic rehabilitation</td>
</tr>
<tr>
<td>21st</td>
<td>3rd Aquatic rehabilitation</td>
</tr>
<tr>
<td>22nd</td>
<td>Completed land-based rehabilitation</td>
</tr>
<tr>
<td>23rd</td>
<td>4th Aquatic rehabilitation</td>
</tr>
<tr>
<td>25th</td>
<td>5th Aquatic rehabilitation</td>
</tr>
<tr>
<td>26th</td>
<td>6th Aquatic rehabilitation</td>
</tr>
</tbody>
</table>

*Day after onset of the injury; **Abbreviations: ROM, range of motion (numbers represent degrees); Flex, flexion; Abd, abduction; Add, adduction; ER, external rotation; IR, internal rotation; Hori Add, horizontal adduction; MWMS, mobilizations with movements; PNF, proprioceptive neuromuscular facilitation; TFM, transverse friction massage.
Aquatic rehabilitation at the pool side during training camp commenced on the 17th day after injury (6 visits total). Joint mobilization of posterior capsule and mobilization with movements (MWMS) in active flexion–abduction–external rotation with the humeral head posteriorinferior gliding (Mulligan, 2004) were applied on the 17th and 18th day. Stretching rotator cuff muscles, taping at supraspinatus, infraspinatus, and teres minor (fig. 2), and education of scapula and humeral head positioning were also performed. In this period, the humeral head still deviated anteriorly, and a painful arc occurred during elevation of the arm. Joint mobility testing indicated limited position of posterior glide of the humeral head because of the tight posterior capsule. Therefore, joint mobilization was applied and MWMS was used to try to correct dynamic alignment and to avoid impingement of the supraspinatus tendon during elevation. After correction of humeral head position, checked taping was applied on the rotator cuff muscles by using a 4-mm wide non-elastic tape to maintain the correct position. Self MWMS was also taught to keep good position of the humeral head on the glenoid during elevation of the arm. On the 21st day, the PT programs were supplemented with MWMS with a 300-g weight (using 300 mL of water in a plastic bottle) and proprioceptive neuromuscular facilitation (PNF) (Myers and Lephart, 2000). At this time, elevation of the arm during front dive did not cause shoulder pain; however, rapid elevation and elevation during back dive caused pain. Therefore, MWMS with a light weight and PNF were applied to improve proprioceptive stimulation for motor learning. From the 23rd to the 26th day, MWMS with a 500-g weight was used, and soft-tissue mobilization such as transverse friction massage (TFM) (Cyriax and Cyriax, 1993) and functional massage (Evjenth and Hamberg, 1984) were added. The reason for increasing the weight during MWMS was to increase proprioceptive stimulation for motor learning. Palpation indicated muscle spasm of the rotator cuff muscles, especially subscapularis. Reaction to the palpation at the supraspinatus tendon indicated that the tendinitis would improve in the recovery stage. Therefore, soft-tissue mobilization was applied in these muscles.

**DISCUSSION**

Rehabilitation in this case study involved immobilization during the acute stage (2 weeks), followed by stability exercises for the glenohumeral joint and scapula, and finally movement toward a functional approach. The rehabilitation program commenced the 5th day after injury; the affected area needed to be rested and other areas trained to keep good condition. On the 13th day, the immobilizing brace was detached, and passive treatments for limited range of motion (ROM), stabilizing exercises for the affected glenohumeral joint, and scapulothoracic exercises were applied. At this stage, the PT program commenced stabilization exercises for the glenohumeral joint to prevent impingement of the rotator cuff. In addition, concentric and eccentric exercises for the rotator cuff were included to induce optimal muscle recruitment during overhead activities of the arm. The scapula plays an important role in facilitating adequate shoulder function to produce efficient movement. The scapular muscles must be dynamically positioned in the glenoid so that efficient glenohumeral movement can occur; therefore, the scapular muscles should be trained optimally.

Being in the subacute stage during the first day of the aquatic rehabilitation, the subject complained slightly of resting pain after elevating the arm and had positive sign of painful arc. Maneuvers of MWMS applied posteriorinferior gliding on the humeral head and mechanically avoided impingement of supraspinous tendon under the coracohumeral arch during active elevation of the arm. MWMS with a light weight (Mulligan, 2004) and PNF facilitated proprioception to gain good motor control of arm movements (Myers and Lephart, 2000). Self MWMS with a light weight was used to gain proper movement patterns of the arm during abduction and adduction. The checked taping was not strong enough to mechanically restrict anterior movement of the humeral head; however, the tape stimulated skin and muscles as light compression during anterior deviation of the humeral head. The tape also stimulated receptors of the skin and the proprioceptors during movements. Although he did not complain of shoulder pain during diving on the day before competition and the day of competition, he was still in the recovery stage. It was evident that he had learned the correct movements of the glenohumeral joint and scapulothoracic junction. Because divers hold extremely elevated positions of the glenohumeral joints and shoulder girdle during the water-entry stage, they can avoid impingement at the middle and final range of elevation by using an appropriate movement pattern and congruous articular position during movements. This rehabilitation program for diving is very sports specific; however, the program could be applied to some sports with a throwing stage, such as wind-up and cocking.

**CONCLUSION**

The rehabilitation program for a diving-related shoulder injury was as follows: (1) during the immobilization stage, general conditioning exercises, such as stretching and strength training of the neck, trunk, and extremities (not including the affected left arm), were applied; (2) after the immobilization stage, joint mobility was addressed, especially posterior capsule and short and tight muscles, then rotator cuff muscles and scapula muscles were strengthened; and (3) an appropriate movement pattern and congruous articular position were achieved during movements by MWMS, PNF, and motor learning.
Comparisons of Water- and Land-based Physical Activity Interventions in Japanese Subjects with Metabolic Syndrome

Hanai, A.¹ and Yamatsu, K.²

¹Hokusho College, Hokkaido, Japan
²Saga University, Saga, Japan

We previously reported that group-based physical activity (PA) intervention had beneficial effects on weight loss in Japanese subjects with metabolic syndrome (MS). Although, water- and land-based PA intervention was often conducted, it is unknown which PA interventions were more effective. The aim of this study was to compare the efficacy of these two interventions in Japanese subjects with MS or several MS risk factors (such as overweight, diabetes, hyperlipidemia). As a result, after 10-weeks, participants in both groups reported significant loss of weight, BMI, and percent body fat. Statistical analyses showed no significant differences between the groups with the exception of daily physical activity levels. It was suggested that both water- and land-based physical activity interventions had short-term beneficial effects on weight loss and reduction of percent body fat.

Key words: Physical activity, Water-based intervention, Land-based intervention

INTRODUCTION

We previously reported that group-based physical activity (PA) intervention had beneficial effects on weight loss and metabolic syndrome (MS) risk factors in Japanese subjects with MS. Although, water- and land-based PA interventions were conducted, it is unknown which PA interventions were more effective. The aim of this study was to compare the efficacy of these two interventions in Japanese subjects with MS or several MS risk factors.

METHODS

Eight subjects with MS or several MS risk factors (such as overweight, diabetes, hyperlipidemia) were selected for either water-based PA intervention (WPI, n=4, Figure 1.) or land-based PA intervention (LPI, n=4). The characteristics of the subjects are shown in Table 1. The contents of exercise program prescribed for WPI and LPI are shown in Table 2. The main outcome measures were body weight, body mass index (BMI), percent body fat and lean body mass (LBM) at trunk, upper and lower limbs (measured by body composition analyzer, TANITA co.) and VO₂max. The daily physical activity (DPA) level was measured by the Kenz Lifecorder EX (SUZUKEN co.) attached to subjects for 1 or 2 weeks, registering the number of daily walking steps. Both interventions had a duration of 10 weeks.

SPSS 14.0J was used for statistical analyses. All values are expressed as means ± SD. Two-way analyses of variance with repeated measures (two-way ANOVA test), Mann-Whitney U test were used for analyses. Statistical significance was set at p<0.05.
RESULTS

After 10 weeks, participants in both groups lost weight (p<0.05), BMI (p<0.001), significantly (Table 3). Although, values of LBM were maintained during the PA intervention in both groups, percent body fat significantly decreased, approximately 3.2 kg for the WPI group, and 2.2 kg for the LPI group (p<0.001). No significant changes were found in VO2max values.

DISCUSSION

Water-based exercise is popular because of the characteristics of water. Buoyancy assistance makes water based activity less physically demanding than exercise on land, and water resistance can be adjusted by changing the speed or direction of the movements. Therefore, it is an effective training strategy for improving physical fitness in those who are overweight or physically unfit. Moreover, because of higher thermal conductivity, caloric consumption is more efficient while exercising in water. Percent changes of body fat at each body part tended to decrease significantly after the water-based PA intervention.

As a result, it appears that the loss of body weight and percent body fat were similar regardless of the selection of PA intervention in short term. However, there is a possibility that the efficacy will differ for long term PA intervention, and further examination might be necessary to investigate the difference of efficacy of water-based and land-based PA interventions.

CONCLUSION

From the results, it was suggested that both water- and land-based physical activity intervention had short-term beneficial effects on weight loss and reduction of percent body fat. However, no significant differences of were found between the interventions. Further research is needed to investigate the differences of efficacy of water-based and land-based physical activity interventions in the long term.

REFERENCES


ACKNOWLEDGMENTS

This study was partly supported by the Grant-in-Aid Northern Regions Lifelong Sports Research center (SPOR).

Table 1. Characteristics of the subjects.

<table>
<thead>
<tr>
<th></th>
<th>WPI group (n=4)</th>
<th>LPI group (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>54.0 (6.5)</td>
<td>57.8 (6.9)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>160.3 (7.5)</td>
<td>155.0 (8.0)</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>67.3 (2.6)</td>
<td>61.5 (2.7)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.3 (2.0)</td>
<td>25.7 (1.6)</td>
</tr>
</tbody>
</table>

WPI: water-based physical activity intervention
LPI: land-based physical activity intervention

Table 2. Contents of exercise program prescribed for WPI and LPI.

<table>
<thead>
<tr>
<th>Exercise Program</th>
<th>WPI</th>
<th>LPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking and jogging, stretching, muscle strengthening with water gloves</td>
<td>Stretching and muscle strengthening, including chair-seated exercise and resistance band exercise</td>
<td></td>
</tr>
</tbody>
</table>

WPI: water-based physical activity intervention
LPI: land-based physical activity intervention

Table 3. Changes of physical characteristics pre-to-post physical activity intervention.

<table>
<thead>
<tr>
<th></th>
<th>WPI groups (n=4)</th>
<th>LPI groups (n=4)</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>67.3 (2.6)</td>
<td>64.4 (2.8)</td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>64.4 (2.8)</td>
<td>61.5 (2.7)</td>
<td></td>
</tr>
<tr>
<td>%Fat (%) trunk</td>
<td>34.7 (10.9)</td>
<td>31.1 (9.5)</td>
<td></td>
</tr>
<tr>
<td>%Fat (%) upper limbs</td>
<td>34.7 (10.9)</td>
<td>31.1 (9.5)</td>
<td></td>
</tr>
<tr>
<td>%Fat (%) lower limbs</td>
<td>34.7 (10.9)</td>
<td>31.1 (9.5)</td>
<td></td>
</tr>
<tr>
<td>LBM (kg) trunk</td>
<td>24.7 (4.0)</td>
<td>24.6 (3.7)</td>
<td></td>
</tr>
<tr>
<td>LBM (kg) upper limbs</td>
<td>24.7 (4.0)</td>
<td>24.6 (3.7)</td>
<td></td>
</tr>
<tr>
<td>LBM (kg) lower limbs</td>
<td>24.7 (4.0)</td>
<td>24.6 (3.7)</td>
<td></td>
</tr>
<tr>
<td>BMX</td>
<td>26.3 (8.5)</td>
<td>26.3 (8.5)</td>
<td></td>
</tr>
</tbody>
</table>

p* Mann-Whitney U test
WPI: water-based physical activity intervention
LPI: land-based physical activity intervention

Table 4. Percent changes of %Fat at trunk, upper and lower limbs.

<table>
<thead>
<tr>
<th></th>
<th>WPI group (n=4)</th>
<th>LPI group (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>trunk</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>85.9 (8.4)</td>
<td>89.5 (5.7)</td>
<td>89.5 (5.7)</td>
</tr>
<tr>
<td>upper limbs</td>
<td>94.7 (3.8)</td>
<td>96.0 (1.6)</td>
</tr>
<tr>
<td>lower limbs</td>
<td>92.6 (3.4)</td>
<td>94.4 (3.4)</td>
</tr>
</tbody>
</table>

* Mann-Whitney U test
WPI: water-based physical activity intervention
LPI: land-based physical activity intervention
Estimation Method for Energy Expenditure by Acceleration of Human Head during Water Walking

Kaneda, K.1, Ohgi, Y.2, Tanaka, C.3

1Research Fellow of the Japan Society for the Promotion of Science, Japan
2Keio University, Japan
3J. F. Oberlin University, Japan

This study aimed at estimating energy expenditure (EE) by accelerations of human head during water walking (WW). Fifty Japanese males (n = 29, age: 27 to 73) and females (n = 21, age: 33 to 70) participated in this study. They conducted WW at three walking speeds of 25 m/min, 30 m/min and 35 m/min. During the WW, an accelerometer was attached to the occipital region of the subjects and recorded three-dimensional accelerations at 100 Hz. We developed estimation equation for EE (kcal/min/kg) including three components of the resting metabolic rate, internal energy expenditure for moving his/her body and energy expenditure against for water drag force. The correlation coefficients were high in both males (r = 0.79) and females (r = 0.77), theoretical estimation equations for EE during WW was developed.

Key words: Energy Expenditure, Estimation, Accelerometer, Water Walking

INTRODUCTION

There are many studies and devices estimating energy expenditure (EE) during land walking, jogging or daily life activities (Kumahara et al., 2004; Scott et al., 2006; Tanaka et al., 2007). Due to its availability, those studies mostly used accelerometers attached to human body (e.g. waist, wrist and ankle). They reported good estimation explained by high correlation coefficient (Scott et al., 2006). However, those studies and devices cannot apply to water exercise because water has specific characteristics compared to air, most prominently water resistance and buoyancy. During exercising in water, the gravitational stress at the lower extremity joint is reduced and greater exert force required for moving (Miyoshi et al., 2005). The metabolic responses during water exercise were different from exercise on land (Masumoto et al., 2008). Until now, we investigated metabolic responses during water walking (WW) for a wide range of Japanese males and females, and cleared that the metabolic responses during the WW were influenced by mostly the walking speed other than the human body size and sex (Kaneda et al., 2009a). Therefore, it is important to develop specific estimation equation for EE during WW for health promotion water exercise. The hypothesis was that the energy expenditure during walking in water was estimated by three components of the resting metabolic rate, internal energy expenditure for moving his/her body and energy expenditure against for water drag force.

We tried to develop estimation equations for EE by accelerations of human head during WW, and this study introduces these methodologies. The future goal is to develop an underwater activity monitor by using an accelerometer.

METHODS

Fifty Japanese males (n = 29, age: 27 to 73) and females (n = 21, age: 33 to 70) participated in this study. The mean characteristics of the subjects are shown in Table 1. They provided a written informed consent to participate in this study, and their health status was examined from screening of medical history and measured blood pressure before each subject’s experiment. This study was approved by the Ethics Committee of Shonan-Fujisawa Campus at Keio University.

The subjects conducted WW at three walking speeds of 25 m/min, 30 m/min and 35 m/min (some subjects executed from 20 m/min and 40 m/min depending on their physical condition), and exercised over 5 minutes at each walking speed. In order to maintain the walking speed steady, a pace-maker walked with the subject on the pool-side. The each walking trial was separated by more than 5 minutes rest period to recover the subject’s condition. The experiment was carried out at the indoor swimming pool (17.2 m length, 5 m width and 1.1 m depth) (Figure 1).

During the each exercise bout, an accelerometer was attached onto the occipital region of the subject and recorded three-dimensional accelerations at 100 Hz. The metabolic responses (VO₂, l/min/kg and VCO₂, l/min/kg) were measured by the Douglas bag method using a portable gas analyzer (AR-1 O2-ro, Arcosystem Inc., Japan) and a dry gas meter (DCDA-2C-M, Shinagawa Corp., Japan). Furthermore, interval times between mid 15 m by stopwatch were also measured at each bout. All analyzed data were selected from last 2 round trips of the each walking trial. The energy expenditure (EE, kcal/min/kg) was calculated by following equation (Weir, 1949) for developing estimation equation from acceleration data:

\[ EE \text{ (kcal/min/kg)} = 3.9 \times VO_2 \text{ (l/min/kg)} + 1.1 \times VCO2 \text{ (l/min/kg)} \]  

Table 1. Characteristics of the subjects, mean±SD.

<table>
<thead>
<tr>
<th></th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (n = 29)</td>
<td>55.0 ± 14.9</td>
<td>170.9 ± 6.1</td>
<td>69.2 ± 9.0</td>
<td>23.7 ± 3.0</td>
</tr>
<tr>
<td>Female (n = 21)</td>
<td>57.4 ± 10.7</td>
<td>156.8 ± 4.6</td>
<td>54.2 ± 5.6</td>
<td>22.1 ± 2.6</td>
</tr>
</tbody>
</table>

Fig. 1. Pool condition in this study.

RESULTS

A total of 160 samples (males: 97 samples, females: 63 samples) were obtained and used for analysis. We considered three components in the estimation equation for the EE (kcal/min/kg): resting metabolic rate (RMR, kcal/min/kg), internal energy expenditure for moving his/her body (joint energy expenditure: EE₃) and energy expenditure for water drag force (EE₄):

\[ EE \text{ (kcal/min/kg)} = \alpha_0 + \alpha_R \text{RMR} + \alpha_3 \text{EE}_3 + \alpha_4 \text{EE}_4 \]  

The RMR was calculated by sex, age and weight based on the basal metabolic rate (BMR) equations in the Dietary Reference Intakes for Japanese (Ministry of Health, Labour and Welfare, Japan, 2010) and multiplied 1.2 for the RMR by Numagiri et al. (1970):

\[ \text{RMR (kcal/min/kg)} = \text{BMR (kcal/min/kg)} \times 1.2 \]  

The EE was assumed to the square root of the sum of squared of both the sagittal (Ay') and vertical (Az') accelerations. For eliminating gravity effect, the acceleration data was corrected by head inclination angle (Figure 2):

\[ Az' = Az - g \cos \theta \]  
\[ Ay' = Ay - g \sin \theta \]
When calculating the EE, the dimensions of the each component must to be equivalent to the mechanical power, and a window of data was set at 5 sec (= \( \Delta t \)) for the purpose of including one cycle during WW (Kaneda et al., 2009b). Therefore, the EE was calculated as follows:

\[
EE = \int_{t}^{t+\Delta t} \sqrt{(A_{x}^2+A_{y}^2)} \Delta t \times \text{weight(kg)} \times v(\text{m/min})/\text{weight(kg)} \tag{6}
\]

where \( v \) is the walking speed measured by stopwatch. The EE was regarded as the anterior-posterior acceleration (\( A_{ap} \)). From the equation (4) and (5), the \( A_{ap} \) is expressed as (Figure 2):

\[
A_{ap} = A_{x} \sin \vartheta + A_{y} \cos \vartheta
\]

Therefore, the EE was calculated as follows:

\[
EE_{wd} = \int_{t}^{t+\Delta t} \sqrt{A_{ap}^2} \Delta t \times \text{weight(kg)} \times v(\text{m/min})/\text{weight(kg)} \tag{8}
\]

The acceleration data was averaged in the last 20 sec of each trial to develop the estimation equation for the EE. The data of the each component was Z-scored.

The results of this estimation equation for the males and females showed in Table 2 and Figure 3, and Figure 4 showed the results of the residual analysis. The correlation coefficients were high in both males (r = 0.79) and females (r = 0.77).

The EE in this study was per unit time. In the view point of mechanics, the EE per unit time can be said as the mechanical power. The mechanical power (\( P \)) is expressed as follows:

\[
P = Fv \tag{9}
\]

where \( F \) is mechanical force and \( v \) is velocity. The mechanical force is expressed as follows:

\[
F = ma \tag{10}
\]

\[
\therefore P = mav \tag{11}
\]

where \( m \) is mass of the object and \( a \) is acceleration. Therefore, we multiplied the body weight and the measured walking speed to the acceleration. And finally, the values were divided by body weight for eliminating the effect of the weight bearing. Until now, we could not find out any previous study adopting such a theoretical estimation method even in land activities. Though the correlation coefficients of the developed equation in this study were high (males: \( r = 0.79 \), females: \( r = 0.77 \)), residual analysis showed large estimation errors, over 30%. We have to continue considering about much reliable method for estimating EE during WW. Moreover, future study about estimation of EE in various water exercise form will be useful for health promotion water exercise.
If an activity monitor that estimates and shows EE during water exercise like activity monitors on land walking, jogging, and life activities (Kumahara et al., 2004; Scott et al., 2006; Tanaka et al., 2007) is developed, water exercise instructors and/or athletes can understand their EE easily and precisely.

CONCLUSION
This study tried to develop specific estimation equation for energy expenditure during water walking. The equation composed three items of resting metabolic rate, internal energy expenditure for moving his/her body and energy expenditure against for water drag force. The correlation coefficients of the estimation equation developed in this study were high (males: $r = 0.79$, females: $r = 0.77$). The future study was needed to develop much reliable estimation equation for energy expenditure during water exercise, although we could develop the theoretical estimation equation. Our future goal to develop an underwater activity monitor by using accelerometer will be useful for health promotion water exercise.

REFERENCES

ACKNOWLEDGEMENTS
The authors acknowledge to the Medical Fitness Club, Fureai Machida Hospital for their agreement and cooperation with successful experiment of this study.

Real and Perceived Swimming Competency, Risk Estimation, and Preventing Drowning among New Zealand Youth

Moran, K.1

1The University of Auckland, New Zealand

Little is known about youth swimming competency or of their perceptions of their risk of drowning. This study reports the New Zealand findings of an international project entitled the Can You Swim Project? The subjects ($n = 68$) were assessed in a two-part study using an initial questionnaire survey to provide self-estimates of swimming competency and risk perception, followed by a practical test of seven swimming competencies. Self-estimates of swimming compared well with actual measurements. Similar proportions were obtained for those who thought they could swim more than 300m (estimated 41%; actual 43%). No significant gender differences in real or perceived swimming competency were found. Significantly more males estimated lower risk of drowning compared with a series of aquatic scenarios. The implications of these findings on drowning prevention and the need for further investigation are discussed.

Key words: swimming competency, risk perception, drowning prevention, water safety

INTRODUCTION
In New Zealand, an island nation with more than 15,000 kilometres of coastline, opportunities to engage in aquatic recreation abound. Whilst participation in recreational aquatic activity is generally perceived as a positive indicator of a healthy lifestyle, it does have attendant risks. In the five years from 2003–2007, a total of 41 New Zealanders aged 15–19 years were fatally drowned. Of these, 66% of victims were male, most incidents occurred in rivers ($n = 23$; 56%) or at beaches/tidal waters ($n = 9$; 22%), and most of the fatal incidents ($n = 30$; 73%) were recreation-related (Drownbase™, Water Safety New Zealand, 2009). Surf lifesaving rescue statistics further illustrate the potential for even greater loss of young lives. During that same 5-year period, 1132 incidents necessitating rescue from the surf were recorded among 16–20-year-olds (SL-SNZ Rescue Statistics, 2009). Males comprised the greater proportion of these rescues ($n = 703$; 62%).

Swimming has been identified as the activity most frequently engaged in prior to drowning in New Zealand (Child and Youth Mortality Review Committee, 2005). Not surprisingly then, the ability to swim has long been promoted by water safety organisations as critical to drowning prevention. However, there is a lack of consensus among water safety experts as to what constitutes swimming competency in the context of drowning prevention (Brenner, Moran et al., 2006), or what swimming-related competencies are important in drowning prevention (Stallman, Junge et al., 2008). While the ability to swim may appear automatic in preventing drowning, some have claimed that the protective effect of being able to swim might be offset by the increased exposure to aquatic risk inherent in utilising that skill (Baker, O’Neil et al., 1992).

Further complicating the association between swimming competency and risk of drowning are the possible underestimation of risk of drowning and overestimation of ability to cope with that risk. Several New Zealand studies have identified a male propensity to take risks during aquatic activities (McCool et al., 2009, 2008; Moran, 2008) and have postulated that this propensity for risk taking rather than differences in risk exposure or swimming competency may help explain why males are overrepresented in the New Zealand drowning statistics. However, no studies have explored the relationship between perceived and real swimming ability, and perceptions of drowning risk. The purpose of this paper is therefore threefold: 1) To assess the swimming competency of
a group of young New Zealand adults, 2) Compare these assessed skills with preconceived estimates of these abilities, and 3) To ascertain self-estimated perceptions of the risk of drowning.

**METHOD**

University students newly enrolled in a four-year professional degree in physical education were invited to voluntarily participate in a study entitled the *Can you swim project*. The study consisted of two phases of data gathering, an initial self-complete questionnaire survey followed by practical swimming assessment prior to the commencement of study in 2008. The study received ethics clearance from the University of Auckland Human Participants Ethics Committee (case no.2007/447).

The self-complete questionnaire contained 20 questions, and was designed to take 10–15 minutes to complete. The written survey sought information on swimming-related competencies, and perceptions of drowning risk. Student estimates of their swimming competency were included in two questions, the first of which provided 5 categories which best described their capacity from *non-swimmer* to *excellent swimmer*, the second of which asked students to estimate the distance they thought they could swim non-stop, using distance categories from <50 metres to >300 metres.

Practical aquatic competency was tested in a 25 metre outdoor heated pool with a 2 metre deep end, using seven tests of aquatic skills including:

- Distance swum non-stop in a 25-metre outdoor heated swimming pool
- Stationary floating in deep-water with minimal swimming motion
- Swim 100m non-stop on back
- Dive headfirst entry into deep water
- Surface dive to deep end of the pool
- Swim underwater a maximum of 25 metres
- Contact rescue tow 25 metres

Perceptions of risk of drowning was assessed via five water-related scenarios depicting differing levels of danger using four response categories ranging from *no risk* to *extreme risk* (for example, *How would you rate the risk to your life in the following situation: tipped upside down in a canoe 100m from the shore of a lake?*).

Data from the completed questionnaires were statistically analysed using SPSS Version 16.0 in Windows. Descriptive statistics were used to report differences in student estimates of swimming competency, and risk perceptions. Mann-Whitney U tests were used to determine significant differences between dependent (such as swimming competency) and independent variables (such as gender).

**RESULTS**

The study included 68 first year students from an intake of 72 enrolments (four were excluded because they were older than 29 years) prior to their commencement of a 4-year undergraduate degree. Of these students, 53% were male (n = 36), and two thirds were aged 17-19 years (69%; n = 47), 22% were aged 20-24 years (n = 15), and 9% were aged 20-29 years (n = 6).

i) **Self-estimates of aquatic competency:** Students were asked how they would categorise their aquatic competency and to estimate their swimming competency in five distance categories (See Table 1). One half considered they were *good/very good* (n = 28; 41%) or *excellent swimmers* (n = 6; 9%), one third considered themselves to be *average swimmers* (n = 25; 37%). One third of the students estimated that they could swim less than 100 m (n = 21; 32%).

<table>
<thead>
<tr>
<th>Swimming competency</th>
<th>Total</th>
<th>Male</th>
<th>Female</th>
<th>Mann-Whitney U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>How would you describe your swimming competency?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non swimmer</td>
<td>2</td>
<td>2.9</td>
<td>0</td>
<td>0.0</td>
<td>2</td>
</tr>
<tr>
<td>Weak/very weak swimmer</td>
<td>7</td>
<td>7.4</td>
<td>2</td>
<td>5.6</td>
<td>5</td>
</tr>
<tr>
<td>Average swimmer</td>
<td>25</td>
<td>36.8</td>
<td>16</td>
<td>44.4</td>
<td>9</td>
</tr>
<tr>
<td>Good/very good swimmer</td>
<td>28</td>
<td>41.2</td>
<td>15</td>
<td>41.7</td>
<td>13</td>
</tr>
<tr>
<td>Excellent swimmer</td>
<td>6</td>
<td>8.8</td>
<td>3</td>
<td>8.3</td>
<td>3</td>
</tr>
<tr>
<td><strong>How far do you think you could swim?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;50 m</td>
<td>11</td>
<td>16.2</td>
<td>4</td>
<td>11.1</td>
<td>7</td>
</tr>
<tr>
<td>51-100 m</td>
<td>10</td>
<td>14.7</td>
<td>8</td>
<td>22.2</td>
<td>2</td>
</tr>
<tr>
<td>101-200 m</td>
<td>12</td>
<td>17.6</td>
<td>7</td>
<td>19.4</td>
<td>5</td>
</tr>
<tr>
<td>201-300 m</td>
<td>7</td>
<td>10.3</td>
<td>4</td>
<td>11.1</td>
<td>3</td>
</tr>
<tr>
<td>&gt;300m</td>
<td>28</td>
<td>41.2</td>
<td>13</td>
<td>36.1</td>
<td>15</td>
</tr>
<tr>
<td><strong>Could you do this in open deep water?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete with difficulty</td>
<td>16</td>
<td>23.5</td>
<td>8</td>
<td>22.2</td>
<td>8</td>
</tr>
<tr>
<td>Complete easily</td>
<td>52</td>
<td>76.5</td>
<td>28</td>
<td>77.8</td>
<td>24</td>
</tr>
<tr>
<td><strong>Can you swim 100 m on your back?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, can swim 100m on back</td>
<td>58</td>
<td>85.3</td>
<td>33</td>
<td>91.7</td>
<td>25</td>
</tr>
<tr>
<td>No, can't swim 100m on back</td>
<td>10</td>
<td>14.7</td>
<td>3</td>
<td>8.3</td>
<td>7</td>
</tr>
<tr>
<td><em>If Yes, could you do this in open deep water?</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete with difficulty</td>
<td>11</td>
<td>16.1</td>
<td>3</td>
<td>8.3</td>
<td>8</td>
</tr>
<tr>
<td>Complete easily</td>
<td>48</td>
<td>86.7</td>
<td>30</td>
<td>90.9</td>
<td>18</td>
</tr>
<tr>
<td><strong>Can you swim underwater?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, can swim underwater</td>
<td>45</td>
<td>66.2</td>
<td>25</td>
<td>69.4</td>
<td>20</td>
</tr>
<tr>
<td>No, can't swim underwater</td>
<td>23</td>
<td>33.8</td>
<td>11</td>
<td>30.6</td>
<td>12</td>
</tr>
<tr>
<td><em>If Yes, how do you feel about this task?</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete with difficulty</td>
<td>27</td>
<td>39.7</td>
<td>5</td>
<td>19.2</td>
<td>22</td>
</tr>
<tr>
<td>Complete easily</td>
<td>19</td>
<td>27.9</td>
<td>21</td>
<td>80.8</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>68</td>
<td>100.0</td>
<td>36</td>
<td>100.0</td>
<td>32</td>
</tr>
</tbody>
</table>

*Significant at the 1% level (2-tailed)

More than one quarter of students estimated that they could swim between 100-300 m (n = 19; 28%) and 41% thought that they could swim > 300 m (n = 28). Most students (n = 52; 76%) reported that they could achieve their estimate easily in open, deep water. No significant differences were evident when estimates of aquatic competency were analysed by gender, the exception being able to swim 25m underwater, where significantly more males than females thought they could easily complete the task (U = 120.000, p ≤ .001).

ii) **Practical swimming assessment:** Students completed seven swimming-related tasks comparable to the items they had been asked to provide estimates of their perceived competencies in the written questionnaire that was completed before the pool tests.
Table 2. Student Aquatic Competencies by Gender

<table>
<thead>
<tr>
<th>Swimming competency</th>
<th>Total</th>
<th>Male</th>
<th>Female</th>
<th>Mann-Whitney U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 m</td>
<td>9</td>
<td>11.3</td>
<td>3</td>
<td>8.3</td>
<td>6</td>
</tr>
<tr>
<td>50-100 m</td>
<td>14</td>
<td>20.6</td>
<td>8</td>
<td>22.2</td>
<td>6</td>
</tr>
<tr>
<td>101-200 m</td>
<td>9</td>
<td>13.2</td>
<td>8</td>
<td>22.2</td>
<td>1</td>
</tr>
<tr>
<td>201-300 m</td>
<td>6</td>
<td>8.8</td>
<td>4</td>
<td>11.1</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 300m</td>
<td>29</td>
<td>42.6</td>
<td>12</td>
<td>33.3</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Floating competency</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2 minutes</td>
<td>5</td>
<td>7.3</td>
<td>2</td>
<td>5.6</td>
<td>3</td>
</tr>
<tr>
<td>6 minutes</td>
<td>8</td>
<td>11.7</td>
<td>7</td>
<td>19.5</td>
<td>1</td>
</tr>
<tr>
<td>&lt; 15 minutes</td>
<td>6</td>
<td>8.9</td>
<td>3</td>
<td>8.3</td>
<td>3</td>
</tr>
<tr>
<td>&gt; 15 minutes</td>
<td>48</td>
<td>70.6</td>
<td>23</td>
<td>63.9</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>100 m swim on back</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not complete</td>
<td>14</td>
<td>20.6</td>
<td>8</td>
<td>22.2</td>
<td>6</td>
</tr>
<tr>
<td>Completed with difficulty</td>
<td>23</td>
<td>33.9</td>
<td>11</td>
<td>30.5</td>
<td>12</td>
</tr>
<tr>
<td>Completed easily</td>
<td>30</td>
<td>44.2</td>
<td>16</td>
<td>44.5</td>
<td>14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dive into pool (2 m depth)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not complete</td>
<td>7</td>
<td>10.3</td>
<td>2</td>
<td>5.6</td>
<td>5</td>
</tr>
<tr>
<td>Completed with difficulty</td>
<td>12</td>
<td>17.6</td>
<td>8</td>
<td>22.3</td>
<td>4</td>
</tr>
<tr>
<td>Completed easily</td>
<td>47</td>
<td>69.1</td>
<td>24</td>
<td>66.7</td>
<td>23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Swim 25 m underwater</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not complete</td>
<td>24</td>
<td>35.3</td>
<td>10</td>
<td>27.8</td>
<td>14</td>
</tr>
<tr>
<td>Completed with difficulty</td>
<td>16</td>
<td>23.5</td>
<td>12</td>
<td>33.4</td>
<td>4</td>
</tr>
<tr>
<td>Completed easily</td>
<td>26</td>
<td>38.3</td>
<td>12</td>
<td>33.3</td>
<td>14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface dive 2 m</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not complete</td>
<td>9</td>
<td>13.2</td>
<td>3</td>
<td>8.3</td>
<td>6</td>
</tr>
<tr>
<td>Completed with difficulty</td>
<td>18</td>
<td>26.5</td>
<td>12</td>
<td>33.3</td>
<td>6</td>
</tr>
<tr>
<td>Completed easily</td>
<td>39</td>
<td>57.4</td>
<td>19</td>
<td>52.7</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rescue contact tow 25 m</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not complete</td>
<td>19</td>
<td>27.9</td>
<td>11</td>
<td>30.6</td>
<td>8</td>
</tr>
<tr>
<td>Completed with difficulty</td>
<td>19</td>
<td>27.9</td>
<td>12</td>
<td>33.3</td>
<td>7</td>
</tr>
<tr>
<td>Completed easily</td>
<td>25</td>
<td>36.8</td>
<td>14</td>
<td>38.9</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 2 shows that almost half of the students (n = 29; 43%) could swim more than 300m non-stop in the 15 minutes time slot allowed. Most students could perform the stationary floating task for more than 15 minutes (n = 48; 70%), the headfirst dive entry into deep water (n = 47; 69%) and the surface dive to two metres depth (n = 47; 69%) and the surface dive to two metres depth (n = 47; 69%). Among the males, the majority of those who could perform the task were able to do so. On average, the males performed the tasks more consistently than the females. However, 33% of the males were unable to swim >100m non-stop and one third (34%) could not stay afloat for more than 6 minutes. The majority of the students (71%) had a sound aquatic skill base. Among the males, the majority of those who could perform the task were able to do so. On average, the males performed the tasks more consistently than the females. However, 33% of the males were unable to swim >100m non-stop and one third (34%) could not stay afloat for more than 6 minutes. The majority of the students (71%) had a sound aquatic skill base. However, given the popularity for aquatic recreation in New Zealand, it is a concern that one third (34%) could not swim >100m non-stop and one fifth of students (19%) could not stay afloat for >6 minutes. Similar concerns have been raised among high school students with one half (n = 1009; 46%) estimating that they could swim 100m (Moran, 2008). Another New Zealand study of 3000 adult beachgoers also reported poor swimming skills with one third (32%) estimating that they could swim <25 m. (McCoo et al., 2008). Unlike other studies on drowning where self-estimates of swimming competency differed between males and females (Quan & Cummings, 2003), this present study found no significant gender differences in self-estimates or actual swimming ability.

As was to be expected from a cohort selected for a programme where aquatic activities were an ongoing part of their professional development, most students had a sound aquatic skill base. However, given the popularity for aquatic recreation in New Zealand, it is a concern that one third (34%) could not swim >100m non-stop and one fifth of students (19%) could not stay afloat for >6 minutes. Similar concerns have been raised among high school students with one half (n = 1009; 46%) estimating that they could swim 100m (Moran, 2008). Another New Zealand study of 3000 adult beachgoers also reported poor swimming skills with one third (32%) estimating that they could swim <25 m. (McCoo et al., 2008). Unlike other studies on drowning where self-estimates of swimming competency differed between males and females (Quan & Cummings, 2003), this present study found no significant gender differences in self-estimates or actual swimming ability.

The findings in relation to perception of the risk of drowning among youth offers support for previous research (McCoo et al., 2009, 2008; Moran, 2008), which argues that young male adults may underestimate the potential dangers inherent in aquatic activities. Even in the most extreme risk scenarios, many males did not rate the risk of drowning highly. These findings of male underestimation of drowning risk offer strong explanatory evidence as to why more young New Zealand males drown than females.

Results from this study should be interpreted with some caution in light of several methodological limitations. The study confined its self-estimated and practical assessment of swimming to beginner students enrolled on a professional degree in Physical Education. It is therefore likely that their estimates of swimming competency might be more accurate than the normal youth population. It would also be anticipated, given their chosen career development, that their incoming swimming competency would be greater than that of other youth and this greater
competency might accurately reflect their ability to cope with risk of drowning. Not withstanding these limitations, the lesser estimations of risk among males in the study does suggest that education aimed at enhancing male youth assessment of drowning risk might help address the over-representation of males in youth drowning and rescue statistics.

CONCLUSION
This paper reports on the first part of an international study that attempts to identify the relationship between real and perceived swimming competency, and perceptions of risk of drowning. The results suggest that participants in this study were realistic in self-estimates of their swimming competency and no significant differences were evident in perceived or actual competency by gender or ethnicity. Males were more likely to underestimate the risk associated with aquatic activity reinforcing previous research findings. Further investigation using similar methodology is required to determine whether these findings are replicated in other populations (without a background in physical education) to ascertain whether others can accurately assess their swimming competency or whether they are likely to overestimate their ability to cope with the dangers inherent in any water-based activity thereby placing themselves at greater risk of drowning.

REFERENCES

Keeping the Safety Messages Simple: The International Task Force on Open-Water Recreational Drowning Prevention

Quan, L.1, Bennett, E.2, Moran, K.1 (co-chairs)

1 Seattle Children’s Hospital/University of Washington, USA
2 Seattle Children’s Hospital, USA
3 The University of Auckland, New Zealand

International Task Force Members:
Beerman S (Canada), Bennett E (USA), Bierens J (Netherlands), Brewster BC (USA), Connelly J (Ireland), Farmer N (Australia), Franklin R (Australia), George P (Australia), Kania J (Kenya), Matthews B (Australia), Moran K (New Zealand), Quan L (USA), Rahman A (Bangladesh), Stallman R (Norway), Stanley T (New Zealand), Szpilman D (Brazil), Tan RMK (Singapore), Tipton M (UK).
Secretariat: Tansik M (USA).

Globally, many organizations addressed the risk of drowning associated with aquatic recreation by promoting a plethora of drowning prevention messages. Preliminary discussion among drowning prevention advocates suggested that messages could be contained within simplified generic messages applicable to all settings. Using a modified Delphi technique to harness expert opinion, the Task Force finally agreed on 16 key messages that would foster open water drowning prevention. Messages were categorized into Care of self and on the Care of others. Learning swimming and water safety survival skills was the dominant message in both categories. It is hoped that by providing simple and consistent prioritised safety messages that are applicable to a range of communities and settings, the ultimate goal of saving lives will be achieved.

Key words: water safety, drowning prevention, recreational drowning, open water

INTRODUCTION
Drowning as a consequence of aquatic recreation is a significant cause of unintentional death worldwide. In many developed countries, aquatic recreation is an integral part of the lifestyle, especially where there is easy access to a wide range of water environments such as beaches, rivers, lakes, and other waterways. While participation in aquatic recreation is generally viewed as indicative of a healthy lifestyle, there are attendant risks of drowning and other water-related injuries (Moran, 2008). In many countries, the highest proportion of drowning deaths occurs in open waters. For example, in Australia, a country renowned for its aquatic leisure pursuits, one third (33%) of the 370 fatalities from 1999-2004 occurred in natural bodies of water, more than half (55%) had been engaged in leisure activity, and swimming had been the activity prior to drowning in one third (33%) of cases (Australian Institute of Health and Welfare, 2008).

Globally, many organizations have attempted to address the risk of drowning associated with aquatic recreation in open water by promoting a diverse plethora of drowning prevention messages. This diversity reflects the multifaceted nature of the drowning problem and has invariably resulted in specific water safety advice relative to particular environments (such as surf beaches or rivers) or specific activities (such as swimming or surfing). Some organizations (such as the International Lifesaving Federation [ILS] at an international level, or the Royal Life Saving Society [RLSS] at a national level) have disseminated information and advice on a wide range of water safety issues. Other organizations have developed expertise in, and engaged in the promotion of, specific aspects of water safety (such as Surf Life Saving Australia [SLSA] for surf safety or New Zealand Coastguard [NZC] for boat...
safety), while others have focused on particular at-risk groups (such as Safe Kids, for children).

While site-, activity-, and group-specific water safety messages are valued components of any targeted promotion, their multiplicity has the potential to obfuscate critical messages or confuse intended recipients. Preliminary discussion among drowning prevention advocates at a workshop in the World Water Safety Conference in Oporto, Portugal, in 2007 suggested that essential advice to the public in general and those in care of others around water might be better promoted primarily within simplified generic messages applicable to all open water recreational settings, all swimming-related activities, and all population groups. As a consequence of this initial discussion, a group of like-minded drowning prevention experts established the International Task Force on Open Water Recreational Drowning Prevention in 2008. It was the purpose of this Task Force to establish simplified guidelines for the promotion of key public water safety messages related to open water recreational drowning prevention.

METHOD

The process of developing the generic open water drowning prevention messages was evolutionary, the initial session was held with approximately 35 people from the Washington State Drowning Prevention Network. It focused on the need to develop water safety messaging for recreational open water settings for parents and families. In addition, the discussion also focused on in-water, swimming-related activity (such as swimming and playing in water) rather than aquatic sports (such as fishing or diving) or craft-related activity (such as boating or surfing). The brainstorming technique was replicated in a workshop during the World Water Safety Conference 2007 in Oporto, Portugal. In response to interest from the international water safety community who shared a collective concern about the ambiguity and inconsistency of water safety messaging, drowning prevention advocates were invited to take part in a task force that would prioritize and provide coherent and consistent safety messages to reduce the risk of drowning during open water aquatic recreation.

From the preliminary workshops and initial rounds of teleconferencing among Task Force members, a list of water safety messages was compiled in a central database. Messages specific to water sites (such as river currents) were separated out of the main list. The messages were then divided into two categories: Care of Self and Care of Others. As a consequence of this process, 65 messages were included in the Care of Self database and 66 in the Care of Others database. Using the Delphi technique to distill the opinions of experts (Brown, 1968), Task Force members were asked to rate the two lists of items by assigning a total of 100 points for messages related to Care of Self and another 100 points for Care of Others. After the first round, points were totaled and only the top 50% of messages were retained. The messages were then reviewed and similar messages were combined. Members were asked for feedback on wording, rationale and any other comments related to the remaining messages prior to the second round of voting. During the second round, messages were ordered by number of points in the first round and all members were able to see the number of points allocated during the first round. After the second round of scoring, the top 50% of messages were chosen.

Two subsequent rounds of voting occurred to approve the wording, combining messages, deleting messages due to lack of supporting information and the final list of messages. All final messages received at least 80% approval by Task Force members and two final rounds of draft documents were sent for review and feedback. Finally, a brief reader friendly rationale and a set of critical actions were developed for messages based on content developed during the message generation process. Full details of the rationale and key actions supporting these key messages are contained in a user friendly version of the findings available at: www.drowning-prevention.org

RESULTS

As a consequence of the multiple rounds of distillation of drowning prevention messages previously described, a total of eight messages for each category—Care for self and Care for others—were ultimately approved (see Tables 1 and 2).

<table>
<thead>
<tr>
<th>Table 1: Key messages of open-water Drowning Prevention: Care of self</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Learn swimming and water safety survival skills</td>
</tr>
<tr>
<td>2. Always swim with others</td>
</tr>
<tr>
<td>3. Obey all safety signs and warning flags</td>
</tr>
<tr>
<td>4. Never go in the water after drinking alcohol</td>
</tr>
<tr>
<td>5. Know how and when to use a life jacket</td>
</tr>
<tr>
<td>6. Swim in areas with lifeguards</td>
</tr>
<tr>
<td>7. Know the weather and water conditions before getting in the water</td>
</tr>
<tr>
<td>8. Always enter shallow and unknown water feet first</td>
</tr>
</tbody>
</table>

Table 1 shows, in descending order of priority, the eight statements that were identified as the most important messages related to Care of self during swimming-related activities in open water environments. Learning swimming and water safety survival skills was seen as paramount in keeping one’s self safe in open water swimming-related recreation. Behind this dominant message, a cluster of three messages were well supported by Task Force members, they included: always swimming with others, obeying all safety signs and warning flags, and never going in the water after drinking alcohol. Other messages to receive moderate support in the final round of distillation included: knowing how and when to use a life jacket, swimming in areas with lifeguards, knowing the weather and water conditions before going in the water, and always entering shallow and water of unknown depth, feet first.

Table 2 shows that, as was the case with Care of self messages, the learning of swimming and water safety survival skills was again the dominant message to prevent drowning when caring for others. Other messages to receive strong support in the Care of Others category all related to safe supervision and included the need to swim under lifeguard supervision, to set and follow rules when caring for others in and around water, and when supervising young children, to always provide close and constant attention without distraction. Knowledge of the use and application of life jackets and the acquisition of first aid and CPR skills were also strongly advocated. Other messages to receive moderate support in the final round of prioritisation included the need to learn safe ways to rescue others without putting yourself in danger and obeying all safety signs and warning flags.
Table 2: Key messages of open-water Drowning Prevention: Care of Others

<table>
<thead>
<tr>
<th>No.</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Help and encourage others, especially children, to learn swimming and water safety survival skills</td>
</tr>
<tr>
<td>2.</td>
<td>Swim in areas with lifeguards</td>
</tr>
<tr>
<td>3.</td>
<td>Set water safety rules</td>
</tr>
<tr>
<td>4.</td>
<td>Always provide close and constant attention to children you are supervising in or near water</td>
</tr>
<tr>
<td>5.</td>
<td>Know how and when to use a life jacket, especially with children and weak swimmers</td>
</tr>
<tr>
<td>6.</td>
<td>Learn first aid and CPR</td>
</tr>
<tr>
<td>7.</td>
<td>Learn safe ways of rescuing others without putting yourself in danger</td>
</tr>
<tr>
<td>8.</td>
<td>Obey all safety signs and warning flags</td>
</tr>
</tbody>
</table>

DISCUSSION
From an original database containing over 60 messages related to care of self and care of others during swimming-related, open water recreation, the Task Force agreed on 16 key messages that would most foster drowning prevention. Learning swimming and water safety survival skills was the dominant message in both Care of self and Care of others categories. The collective reasoning supporting this dominance was that being able to swim reduced the chance of a serious incident in or near the water, but the Task Force reiterated that swimming ability alone was no guarantee of safety. Most people learned to swim in a pool or calm water setting, but this does not fully prepare swimmers for open waters such lakes, rivers or beaches and even good swimmers can encounter life-threatening problems. Swimming safely in any open water therefore requires special caution since different types of open water have changing risks such as cold, currents and high waves (Golden & Tipton, 2002).

Task Force members concurred in the belief that swimmers should never underestimate the risk of drowning or overestimate their ability to cope with those risks during aquatic activity (Michalsen, 2006). Thus water safety was deemed to be more than just swimming competency; it was also about having the knowledge and attitudes to be safe in and around water. In the case of caring for others, it was further reasoned that encouraging others, especially children, to learn swimming and water safety survival skills was a prime responsibility, especially for parents and caregivers.

Another strongly supported message in both Care of self and Care of others categories related to swimming with lifeguard supervision (ranked second and sixth respectively). While recognizing that no water is ever completely free from risk, evidence of the efficacy of lifeguard supervision in drowning prevention is compelling (for example, Branche & Stewart, 2001). Lifeguards are trained to promote safe behavior around the water and to prevent drowning by helping those in distress through the provision of rescue and medical assistance. A key part of the safety actions advised by the Task Force was for people to check with the lifeguards for safety advice about the location before entering the water. They also noted that, when caring for others even at a life-guarded location, the onus of supervisory care was still primarily that of the parent or caregiver. Furthermore, that supervision should be close, constant, and without distraction.

Several important messages focused on the personal application of safety rules in the Care of self category. These included: always swim with others (ranked second), obey all safety signs and warning flags (ranked third), never mix swimming with alcohol (ranked fourth), and know the weather and water conditions before getting in the water (ranked seventh). The safety value of swimming with others was predicated on the knowledge that many drowning deaths involve people swimming alone and that immediate assistance in the event of difficulty and the ability of others to signal or call for help would minimize the risk of drowning. The fourth-placed ranking given to never mixing alcohol with swimming reflected the incidence of alcohol-related drowning fatalities, and because alcohol exacerbates cold water immersion effects, and impairs judgment.

The message to obey all safety signs and warning flags (ranked third in Care of self and eighth in Care of others) was grounded in the importance of informing the public of potential hazards in order that they can make informed decisions about their safety. Safety signs may contain prohibition notices (such as surfing only or no swimming), warning signs (such as strong currents or deep water) or mandatory signs (such as wear a lifejacket) (Sims, 2006). Flags are often used to show areas patrolled by lifeguards (such as red and yellow flags), restricted areas (such as black and white quartered flags for surfing only), or flags indicating weather and water conditions (such as red flags for dangerous conditions or closed beaches).

The use of lifejackets (PFD’s), traditionally associated with boating and land-based fishing safety, ranked fifth in both categories and was deemed important in open water swimming activity especially where immersion was likely to lead to involuntary submersion (Brooks et al., 2006). It was especially noted that lifejackets provided safety in the water especially for children, weak, tired or injured swimmers.

In the Care of others category, the Task Force strongly supported messages related to supervision skills, notably the setting of water safety rules (ranked third), the provision of close and constant attention of children (ranked fourth), as well as the lifesaving skills of learning first aid and CPR (ranked sixth) and safe rescue techniques (ranked seventh). In the latter, because would-be rescuers sometimes become victims in multiple drowning tragedies, caution about personal risk was a focal point in discussion and advice for intervention focused on the acquisition of non-immersion, non-contact rescue techniques.

Results of this project should be treated with some caution in light of several methodological limitations. Firstly, the self-appointed Task Force may not have been wholly representative of the drowning prevention community. High income level countries whose incidence of drowning are highly related with frequent recreational water use were over-represented compared to low income level and regions whose drowning rates may not be linked to aquatic recreation. Secondly, members were more likely to be involved in surf and ocean settings than lakes and river recreational activities. Fourthly, lack of universally agreed terminology and language constraints placed limitations on the meaning of messages. We anticipate that various cultures and languages will need to interpret the recommendations with caution so as to reduce the risk of loss of meaning in translation. Finally, the group was not sanctioned nor funded by any global organization so participation was voluntary and constrained by other professional commitments and personal resources. These limitations notwithstanding, the generic water safety messages provide a comprehensive, concise and universal framework for communicating open water drowning prevention messages at an international, national, regional, and community level.

CONCLUSION
The recommendations have established informed, consistent, and concise messages that promote safe recreational use of open water. It is hoped that they will improve the clarity of communication between drowning prevention organizations and the public they serve as well as provide a framework for safety messaging that is applicable to a range of communities and settings with the ultimate goal of saving lives.
REFERENCES


ACKNOWLEDGEMENTS

The Task Force wishes to acknowledge the work of the participants and their member organizations, the contributing organizations who reviewed the findings and especially Martha Tansik for her patience and persistence, her attention to detail and her meticulous recording of due process.

Immune Status Changes and URTI Incidence in the Initial 7 Weeks of a Winter Training Season in Portuguese Swimmers

Rama, L.1, Alves, F.B.2, Rosado, F1, Azevedo, S.1, Matos, A.1, Henriques, A.1, Paiva, A.3, Teixeira, AM.1

1Research Centre for Sport and Physical Activity, University of Coimbra, Portugal,
2Faculty of Human Kinetics, Technical University of Lisbon, Portugal,
3Histocompatibility Centre, Coimbra, Portugal

In swimming the training planning process usually leads to a sudden increase of training load in the first mesocycle of the season. Swimmers often come back from off training periods unfit, so this option could result in a maladaptation condition with impact on the work capacity and health of the athletes. This study focused on the variation of hormonal and immune markers, and in the occurrence of upper respiratory tract infection symptoms (URTIS) registered during the first mesocycle of preparation, of a winter season, in a group of male swimmers. Results show that the higher rate of URTIS of the training season occurred in this period. At rest, an increase in leukocyte counts and a decrease in CD4+, CD8+ and NK cell counts were found. The increased serum cortisol levels and the decrease in the testosterone/cortisol ratio, could lead to a diminished immune competence observed.

Key words: Upper respiratory symptoms, training load, lymphocyte sub populations, cortisol, testosterone

INTRODUCTION

Despite different periodization strategies, there is a known trend for a substantial increase in training volume in the initial mesocycle of the training season (Costill et al. 1992). Few studies specifically address this initial adaptation period of training. The remarkable impact of this phase is generally overlooked by coaches, given the low intensity and gradual increment of training load. However, swimmers frequently come from off training periods in unfit condition, so this training phase could produce an important impact as a stress factor.

Coaches admit that swimmers often become ill during hard training periods, especially during and after cycles of preparation in which they are submitted to large volumes of training. It is also reported by coaches that athletes often show a higher occurrence of upper respiratory tract infection symptoms (URTIS) during this period (Spence et al. 2007).

Among several markers, hormonal responses have been used to monitor how swimmers adapt to acute exercise, training sessions and even larger periods of training (Urhausen et al. 1995). In spite of some controversies related to the hormonal and immunological alterations in response to training, these parameters may reflect the adaptation process. It is usually assumed that cortisol increases (Bonifazi et al. 2000) while testosterone decreases (Tyndall, et al. 1996) during and after important aerobic training cycles.

Due to the well-established interdependence between hormonal and immune function, namely the influence of cortisol on lymphocytes counts it is not surprising that the immune response to hard training periods occurs in the form of a depression state (Gleeson, 2007).

There are few studies that address the chronic training effects on immune parameters, however the main ones reported are those that show alterations that occur with T cells, and include lower cells count values and diminished proliferative capacity (Gleeson, 2006).

In a longitudinal study over a competitive season with high level Australian swimmers, no alterations were found for B or T cells, but significant decreases on count and percentages of NK cells were noted (Gleeson et al. 1995). NK cells were considered based on their prevalence and function. The majority of NK cells (~90%) are NK1+ with...
more cytotoxic capacity, and NK\textsuperscript{dim} (10\%) with a higher affinity to IL-2 and a large capacity to produce cytokines: IFN-\gamma, TNF-\beta, GM-CSF, IL-10, IL-13 after monokine stimulation (Cooper et al. 2001). The striking sensitivity of NK cells to exercise stress provides strong support that these cells may be implicated as a potential link between regular physical activity and overall health status (Timmons & Cieslaak, 2008).

However the results are not without some controversy, as a large number of studies are conducted in vitro assays, and when peripheral blood samples were used, it was not possible to determine the true nature of the alterations observed in the immune parameters: whether it is a decrease in immune function or an adaptive mechanism such as changes in the cells redistribution patterns.

The aim of this study was to analyze the variation of hormonal and immunological parameters and the incidence of URTIS, during the first 7 weeks of a winter training season in a group of national level Portuguese male swimmers.

**METHODS**

This study sample consisted of 13 male swimmers of Portuguese national level (17.2 ± 1.3 years old, 174.9 ± 5.8 cm, 65.8 ± 6.8 kg of height and weight respectively). All subjects gave their written informed consent.

Training volume and intensity were controlled as well as the time spent in dry land activities. Blood samples were collected: 1) in the beginning of the winter season, after an off training period of 6 weeks (t0), 2) after 7 weeks of training (t1), by venopuncture, always at the same time of the day (between 15 and 17h). At t1 a time lapse of 48 hours of rest after the last training session was respected.

Total leukocyte counts and percentage were measured on a Coulter counter diff TM Analyser. The lymphocyte populations and subsets (CD3\textsuperscript{+}, CD4\textsuperscript{+}, CD8\textsuperscript{+}, CD19\textsuperscript{+} and CD56\textsuperscript{+}) were accessed by flow cytometry (FACSCalibur; BD, San Jose, C.A., USA).

The serum concentration of cortisol and free testosterone were determined by electrochemiluminescence (Immulite 2000) at the same time points. The URTIS were assessed by self-report in daily log books. Statistical analysis using the non-parametric Wilcoxon test was conducted (p<0.05) for detection of differences between evaluation moments.

**RESULTS**

During the study period, the volume of training increased gradually until the weekly distance swim doubled (from 20 km to 42 km) in a mean rate of 17.5% increase/week. This workload represents a mean of 16 to 20 hours of pool training and 3 to 5 hours of dry land training.

The most pronounced rate of URTIS occurrence, of all the winter swimming season. URTIS were observed during this 7 week period (affecting 53.8% of the athletes, representing 0.6 episodes/swimmer). The leukocyte counts showed a significant increased from 7.2 ± 0.8 to 9.1 ± 103.\muL^{-1} (p<0.01) corresponding to a significant elevation in granulocyte counts and percentage (62.2 ± 7.7 to 67.4 ± 6.4 %; p<0.01).

The total number of lymphocytes remained unchanged but the CD4\textsuperscript{+} (Th) and CD8\textsuperscript{+} (Tc) cell counts, and not the percentage, decreased significantly (from 308.7 ± 194.7 to 187.7 ± 75.0 and 193.6 ± 148.8 to 109.8 ± 56.9 cells.\muL^{-1} for CD4 and CD8 respectively; p<0.05).

The CD4 to CD8 ratio and the number of CD19\textsuperscript{+} cells showed no significant alterations. The CD56\textsuperscript{+} cells exhibited significant lower numbers (176 ± 136 to 101 ± 65 cells.\muL^{-1}; p<0.01) and percentage (6.0 ± 2.5 to 4.9 ± 2.1; p<0.05). Looking at the NK subsets we found a significant decrease of NKCD56\textsuperscript{dim} and the opposite increase of NKCD56\textsuperscript{dim} cells.

Serum cortisol concentration increased significantly (79.35 to 110.44 ng.mL\textsuperscript{-1}; p<0.05), contrarily to free testosterone concentration that remained unchanged, producing a testosterone to cortisol ratio significantly decreased (0.16±0.06 to 0.12±0.05; p< 0.05).

| Table 1. Hormonal and immune parameters (mean ± sd) before the beginning of the winter swimming season (t(0)) and after the first 7 weeks of the training season (t(1)) |
|-----------------------------------------------|----------------|----------------|--------------------------|
|                  | t(0)           | t(1)           | p               |
| Leucocyte (x10\textsuperscript{3}.\muL\textsuperscript{-1}) | 7.2 ± 0.8      | 9.1 ± 2.1      | 0.006         |
| Granulocyte (x10\textsuperscript{3}.\muL\textsuperscript{-1}) | 4.5 ± 0.7      | 6.4 ± 1.9      | 0.004         |
| Granulocyte (%)  | 62.2 ± 7.7     | 67.4 ± 5.6     | 0.006         |
| Lymphocyte (cells.\muL\textsuperscript{-1}) | 2627 ± 756     | 2618 ± 625     | ns             |
| Lymphocyte (%)   | 30.3 ± 6.8     | 28.1 ± 6.4     | ns             |
| CD3\textsuperscript{+} (cells.\muL\textsuperscript{-1}) | 1710.2 ± 532.5 | 1729.3 ± 465.5 | ns             |
| CD3 (%)          | 19.6 ± 4.6     | 18.5 ± 4.6     | ns             |
| CD4\textsuperscript{+} (cells.\muL\textsuperscript{-1}) | 308.7 ± 194.7  | 187.7 ± 75.0   | 0.002         |
| CD4\textsuperscript{+} (%) | 59.2 ± 6.1     | 61.2 ± 7.1     | ns             |
| CD8\textsuperscript{+} (cells.\muL\textsuperscript{-1}) | 193.6 ± 148.8  | 109.8 ± 56.9   | 0.009         |
| CD8\textsuperscript{+} (%) | 35.1 ± 5.6     | 34.0 ± 6.0     | ns             |
| CD4/CD8          | 1.8 ± 0.5      | 1.9 ± 0.5      | ns             |
| CD19\textsuperscript{+} (cells.\muL\textsuperscript{-1}) | 373.3 ± 116.1  | 370.3 ± 103.8  | ns             |
| CD19\textsuperscript{+} (%) | 4.3 ± 0.9      | 3.9 ± 0.7      | ns             |
| CD56\textsuperscript{+} (cells.\muL\textsuperscript{-1}) | 176 ± 136      | 101 ± 65       | 0.005         |
| CD56\textsuperscript{+} (%) | 6.0 ± 2.5      | 4.9 ± 2.1      | 0.025         |
| NK\textsuperscript{dim} (cells.\muL\textsuperscript{-1}) | 95 ± 3         | 66 ± 12        | 0.001         |
| NK\textsuperscript{dim} (%) | 168 ± 133      | 68 ± 49        | 0.001         |
| NK\textsuperscript{dim} (cells.\muL\textsuperscript{-1}) | 5 ± 3          | 34 ± 12        | 0.002         |
| NK\textsuperscript{dim} (%) | 7 ± 4          | 33 ± 19        | 0.028         |
| Free Testosterone (pg.mL\textsuperscript{-1}) | 12.2 ± 6.3     | 12.2 ± 7.2     | ns             |
| Serum cortisol (ng.mL\textsuperscript{-1}) | 79 ± 35        | 110 ± 44       | 0.046         |
| T/C              | 0.16±0.064     | 0.119 ± 0.055  | 0.028         |

**DISCUSSION**

The total training load and the increment of the volume in this study compare well to those reported for high international level swimmers (Maglischo, 2003). The rate of increment of training stimulus was thought to be prudent, however our results show a real impact observed in hormonal and immunological parameters.

This study was held in September-October before the seasonal peak flu. The number of URTI episodes is slightly higher but not very different from that expected for the normal population ~0.2 to 0.4 per month (Heath et al. 1992; Cox et al. 2004). Although it was not possible to control the etiology of the symptoms (allergy, infection, inflammation), during this initial training phase the prevalence of URTIS was the highest of the training season.

The increase in cortisol is in agreement to that reported before (Bonifazi et al. 2000) and could correspond to a metabolic and inflammatory condition related to training. In this study the free testosterone concentration did not seem be affected by aerobic training which is in accordance with other studies (Mujika et al. 1996).

When analysing these results it is important to stress that before the blood collection a time lapse of 48 hours of off training activities was respected, as it rules out the influence of acute exercise on the immune system as cause of leucocytosis. The elevation of granulocytes may probably reflect an inflammatory state related to the increment of the training load. It has been referred that the decrease in CD4\textsuperscript{+} counts rarely leads to compromised immunity as it is due mostly to trafficking and distribution alteration (Nagatomi, 2006), however the remarkable lower cells number could account to immune suppression. The decrease observed in lymphocyte cell counts subsets that could explain a lower immune competence seems to be associated with the elevation of cortisol, known by its suppressive effect on lymphocyte function (Shinkai et al. 1996). However, a redistribution alteration due to the influence of cortisol has been reported, with the lung, bone marrow and liver assuming the potential sites of lymphocytes destination (Nagatomi, 2006).

The alteration observed in NKCD56 counts and percentage is in line of previous research (Gleeson et al. 1995). The NK population is consid-
ered the most responsive of the innate immune system, being cytotoxic and producing cytokines against target cells. Our data shows that the count and the percentage of NK cells tend to exhibit a decrease in the total NK population. In addition, the significant alterations observed in NK cell subsets, with the NKCD56dim subpopulation showing reduced cell numbers, could represent an impairment of cytotoxic activity with consequences in immune function. The elevation of the NKCD56bright/NKCD56dim ratio has been associated with a fall in cytotoxic activity (Susui et al. 2004).

In this study, no significant alterations in B lymphocyte (CD19+) cell counts and percentage were observed which is in accordance to previous published papers (Gleeson et al. 1995).

CONCLUSION
The presented data confirm that alterations in the immune system may occur during training periods. The real meaning of this response behaviour, immune depression or adaptation process is still inconclusive.

The main findings of this study point to an impact on immune function of progressive and light training loads at the initial phase of preparation, after long periods of rest, which should be taken into account by the coaches when adopting recovery strategies aimed at reducing the negative impact of training. The results also stress the importance of the use of daily logs or other strategies to monitor how athletes are adapting to workload, which could be useful in detecting early signs of difficulties in this process. For example, preventive measures like nutritional supplementation or training load adjustment could be implemented. Also important is the medical care support at times of intensified training load, allowing for a rapid diagnosis and treatment of the episodes of illness recorded.

In his study, we did not look at the immune cells function, so there is always the possibility that the alterations observed could be related to blood redistribution factors. However, the prevalence of URTIS observed seems to reflect a real negative impact on immune function and to the importance of monitoring the effects of training load in athletes.

REFERENCES


Shinkai, S., Watanabe, S., Asai, H. & Shek, P. N. (1996). Cortisol re-

sponses to exercise and post-exercise suppression of blood lymphocyte subset counts. *Int J Sports Med*, 17(8), 597-603.


ACKNOWLEDGEMENTS
This project was financed by the Portuguese foundation for Science and Technology (FCT PTDC/DES/68647/2006).
Swimming Ability, Perceived Competence and Perceived Risk among Young Adults

Stallman, R.K.1,2, Dahl D.1, Moran, K.1, Kjendlie, P.L.1,4
1Norwegian School of Sport Science,
2Norwegian Life Saving Association,
3Univ. of Auckland,
4Vestfold University College

Why do swimmers get into trouble? Do they over estimate their ability, underestimate the risk, both? Eighty one (n = 81) university physical education students completed a questionnaire and performed seven practical swimming tests. The questionnaire covered a) perception of ability, b) perception of difficulty in open water and c) perception of risk. Gender differences were tested by the Mann-Whitney U test. The women out performed the men on 4 of 7 practical tests. There were few gender differences in perceived competence. The women were highly confident about floating in open water while the men were certain they could not do the same. The men predicted 100% success on surface diving to the bottom of the pool (4m) while the women were less certain (88%). On 5 scenarios depicting risk, there were no gender differences.

Key words: swimming ability, perceived competence, perceived risk

INTRODUCTION
This study presents the results of an attempt to compare young adult’s perception of their ability in the water to their real ability. These are the Norwegian findings in a larger international project, Can You Swim? Water Safety experts generally believe that water safety education must include knowledge, attitude, judgment and skill. One of the most important elements of knowledge is to know your own limits. The ‘deadly duo’ of over estimating ones ability and under estimating the risk (in any given specific situation) can have fatal consequences. McCool et al. (2009) examined exactly this in New Zealand; to what degree do beach goers perceive risk? New Zealand is well known for it’s aquatic recreational opportunities and it is normally considered a sign of an active healthy life style that young people participate as much as they do. In New Zealand swimming is the activity most often engaged in prior to a drowning episode (2005). In Norway, a considerable majority of drownings are related to small boat use and alcohol is often involved (Norwegian Peoples Aid, 2007).

It has been speculated however, that increasing the swimming competency of any society may in fact increase exposure to risk (Baker et al, 1992). It is thus doubly important in any water safety – drowning prevention effort, to insist that the teaching of swimming include more than only skills. Risk assessment needs to be a routine affair for persons frequently engaging in aquatic recreation. This cannot be a general kind of orientation but must address real local conditions.

It is also well known that in other daily pursuits, men frequently are greater risk takers than women. An excellent example of this is the dramatic over representation of men among traffic injuries and among those penalized for reckless driving and driving while intoxicated (Trygg Trafikk, 2008). Studies in New Zealand have identified men as greater risk takers in aquatic activity than women (McCool et al, 2008, 2009, Moran, 2008). There appears to be little available information on the relationship between real aquatic competency and perceived competency. The goals of this study were to a) assess the swimming ability of university students, b) to assess perceptions of swimming ability and risk, and c) to compare real and perceived competency.

METHOD
Eighty one (n = 81) university physical education students participated in the study. The subjects were first year students and all testing was conducted in the first days of the school year, before they were exposed to swimming instruction. They first answered a questionnaire which required less than 30 min. The questionnaire (20 questions) covered a) perception of swimming ability (can you swim > 50, 100, 200, 300m?, etc), b) perception of whether or not the same skills could be accomplished in open water, and c) perception of risk in five specific scenarios.

The practical tests consisted of seven skills considered essential (Table 1). Table 1 lists the questions used to elicit perceived competence as well as the perception of difficulty on the same skills in open water.

Table 1  Practical Tests and Criteria for Success

<table>
<thead>
<tr>
<th>Test</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance swim (25m pool)</td>
<td>&gt;2, &gt;4, &gt;8, &gt;12, &gt;16 lengths, non-stop</td>
</tr>
<tr>
<td>Floating in deep water</td>
<td>cannot float, &lt;2min, &lt;4min, &lt;6min, &lt;10min, &lt;15min</td>
</tr>
<tr>
<td>Swim on the back</td>
<td>4 pt scale, poor to excellent form</td>
</tr>
<tr>
<td>Dive into deep water</td>
<td>4 pt scale, poor to excellent form</td>
</tr>
<tr>
<td>Swim under water</td>
<td>&gt;10, &gt;15, &gt;20 or 25m</td>
</tr>
<tr>
<td>Surface dive to 4m depth</td>
<td>Failed &amp; 4 pt scale, poor to excellent form</td>
</tr>
<tr>
<td>Rescue towing</td>
<td>25m with mannequin, DNF &amp; 4 pt scale, poor to excellent</td>
</tr>
</tbody>
</table>

Table 2  Perceived Competence

<table>
<thead>
<tr>
<th>Question</th>
<th>Scoring scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do you rate your swimming ability?</td>
<td>very weak, weak, aver., good, very good</td>
</tr>
<tr>
<td>How many lengths (25m pool) can you swim?</td>
<td>&gt;2, &gt;4, &gt;8, &gt;12, &gt;16 lengths</td>
</tr>
<tr>
<td>How do you feel about doing this in open water?</td>
<td>very difficult, difficult, easy, very easy</td>
</tr>
<tr>
<td>Can you swim 100m non-stop on your back?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Can you dive into the deep end of the pool?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>How do you feel about doing this?</td>
<td>very difficult, difficult, easy, very easy</td>
</tr>
<tr>
<td>Can you swim underwater along the length of the pool?</td>
<td>&gt;10, &gt;15, &gt;20, 25m</td>
</tr>
<tr>
<td>How do you feel about doing this?</td>
<td>very difficult, difficult, easy, very easy</td>
</tr>
<tr>
<td>Can you surface dive to the bottom of the pool (4m)?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>How do you feel about doing this?</td>
<td>very difficult, difficult, easy, very easy</td>
</tr>
<tr>
<td>Can you rescue someone in deep water?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>How do you feel about doing this?</td>
<td>very difficult, difficult, easy, very easy</td>
</tr>
</tbody>
</table>

The subjects were also asked to rank their perception of risk as; no risk, slight risk, high risk, extreme risk, on five descriptive risk scenarios which were water related. Table 3 shows the description of these scenarios. The data were analyzed using SPSS 16. Gender differences were calculated by the Mann-Whitney U test.

Table 3  Risk Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Capsize in canoe, well off shore</td>
</tr>
<tr>
<td>2. Caught in rip current at unpatrolled surf beach</td>
</tr>
<tr>
<td>3. Chased toy into deep end of pool</td>
</tr>
<tr>
<td>4. Fell into deep river fully clothed</td>
</tr>
<tr>
<td>5. Swept off isolated rocks while fishing</td>
</tr>
</tbody>
</table>

RESULTS
As can be seen in Table 2, the women out performed the men significantly on four of seven tests, with a fifth showing close to significant superiority for the women.
Regarding perceived competence, both the men (87.2%) and the women (76.5%) rated themselves as average to good swimmers. Although the difference was not significant, the practical tests (item 2, can swim >400m) showed that the women (100%) were, in fact, slightly better than the men (97.9%).

The next 14 questions, only two showed a significant gender difference. The women were highly confident about floating in deep water (83.7%) while the men (only 6.3%) were convinced that they could not do this. This was in accordance with reality as 91.5% of the men failed to float at all, while only 73.5% of the women failed. The second question showing gender difference was regarding surface diving to the bottom of the pool. One hundred percent (100%) of the men predicted they would do this while 88.2% of the women predicted success. The practical test did not confirm the prediction. Among the men, 95.7% managed the surface dive but 97.9% of the women managed it. Although the difference appears to be small, it was never the less, statistically significant.

The perceived risk of drowning as indicated by ranking risk from 1-4 on five water related scenarios, showed no differences between the men and the women. In general, only one of the five scenarios elicited reports of high perceived risk.

### DISCUSSION

That the women would so clearly out perform the men was not expected. Of educational significance is the fact that despite significant gender differences on real competence, both the men and the women performed relatively poorly on a) floating in deep water, b) swimming on the back and c) both surface diving and swimming under water and d) the rescue tow. All of these skills have a real survival value and need to be addressed. Regarding floating, Stallman (1999) showed that with a full inspiration, all women (100%) and >90% of all men, have the capacity to float. Those who failed to live up to their anatomical capacity, clearly lacked only confidence. When discussing confidence skills, it has often been stated that there are no objective measures of confidence in the water. When an individual has the proven (measured) anatomical capacity to float and fails to do so, there can be no better ‘objective’ test of confidence. Among these subjects (men and women), a full 84% failed to float in deep water. A total of 42%, nearly half of the subjects, swim poorly on the back in spite of ranking themselves as average to good swimmers. Over half of the total surface dived with only satisfactory or poor form and one third (34.2%) could not swim >15m under water. This should be a cause for alarm when dealing with university students who have been through compulsory swimming instruction in primary school.

In much of the world, swimming instruction can be held outdoors for only a small part of the year. Even where this would be practical, outdoor pools are often used. The consequences of this are that an increasing number of people have learned to swim in a pool. In some parts of the world, swimming in open water is simply too dangerous because of the threat of predators and/or microbes. However it is well known that drowning occurs primarily in open water. Those who do not survive an aquatic episode have usually failed to make the transition from the learning atmosphere to the recreational or working atmosphere. Seven of the questions about perceived ability were followed by the question, ‘How do you feel about doing this? or ‘how do you feel about doing this in open water?’ Using only one of the open water questions as an example; 43.2% of the total rated themselves as good to excellent swimmers and 65% said they were able to swim >400m. However, 64.2% answered that they could do the same in open water as in the pool only with difficulty or with great difficulty.

The subjects in this study had previously demonstrated that they could swim, in a physical entrance test which all applicants to the school must perform. This would suggest that they are above average compared to their age mates. This can only mean that the general public would have performed more poorly.

### CONCLUSIONS

The women performed significantly better than the men on 4 (5) of seven skills but both performed poorly on several critical skills. This is of concern. Also, it would appear that on two of the seven skills the subjects were not able to accurately predict their level of competence. Contrary to expectations, there were no gender differences in perception of risk.

Lastly, while 43% (men and women) reported that they were good to very good swimmers, they performed only from mediocre to poor on 5 of seven tests. And while performing at only a moderate to poor level, they reported high risk on only one of the five risk scenarios. It would appear that they were reasonably good at predicting their competence on specific skills but were unable to assess their general level of competence or to relate it to their level of performance on specific skills. Their perception of what is a good swimmer was skewed.

### REFERENCES


---

**Table 4** Results of practical tests by gender

<table>
<thead>
<tr>
<th>Practical Test</th>
<th>Score</th>
<th>Male n %</th>
<th>Female n %</th>
<th>Total n %</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance swim</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 8 lengths</td>
<td>1</td>
<td>1.2</td>
<td>0</td>
<td>1.2</td>
<td>0.40</td>
</tr>
<tr>
<td>8-16 lengths</td>
<td>46</td>
<td>97.9</td>
<td>34</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>Float</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 4 min</td>
<td>0</td>
<td>0.0</td>
<td>1</td>
<td>2.9</td>
<td>1.2</td>
</tr>
<tr>
<td>&lt; 8 min</td>
<td>4</td>
<td>8.5</td>
<td>8</td>
<td>23.5</td>
<td>12.48</td>
</tr>
<tr>
<td>Swim on back</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor form</td>
<td>22</td>
<td>47.8</td>
<td>12</td>
<td>35.3</td>
<td>34.25</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>16</td>
<td>34.8</td>
<td>10</td>
<td>29.4</td>
<td>26</td>
</tr>
<tr>
<td>Good</td>
<td>8</td>
<td>17.4</td>
<td>10</td>
<td>29.4</td>
<td>18.25</td>
</tr>
<tr>
<td>Excellent</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>2.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Dive into deep</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>9</td>
<td>19.1</td>
<td>3</td>
<td>8.8</td>
<td>12.48</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>24</td>
<td>51.1</td>
<td>13</td>
<td>38.2</td>
<td>37</td>
</tr>
<tr>
<td>Good</td>
<td>14</td>
<td>29.8</td>
<td>17</td>
<td>50</td>
<td>31.83</td>
</tr>
<tr>
<td>Excellent</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>2.9</td>
<td>1.2</td>
</tr>
<tr>
<td>Under water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;10m</td>
<td>7</td>
<td>15.2</td>
<td>6</td>
<td>18.2</td>
<td>13</td>
</tr>
<tr>
<td>&gt;15m</td>
<td>8</td>
<td>17.4</td>
<td>6</td>
<td>18.2</td>
<td>14</td>
</tr>
<tr>
<td>&gt;20m</td>
<td>7</td>
<td>15.2</td>
<td>7</td>
<td>21.2</td>
<td>14.77</td>
</tr>
<tr>
<td>&gt;25m</td>
<td>24</td>
<td>52.2</td>
<td>14</td>
<td>42.4</td>
<td>38.48</td>
</tr>
<tr>
<td>Surface dive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>2</td>
<td>4.3</td>
<td>1</td>
<td>2.9</td>
<td>3</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>31</td>
<td>66.0</td>
<td>10</td>
<td>9.4</td>
<td>41</td>
</tr>
<tr>
<td>Good</td>
<td>13</td>
<td>27.7</td>
<td>18</td>
<td>52.9</td>
<td>31</td>
</tr>
<tr>
<td>Excellent</td>
<td>1</td>
<td>2.1</td>
<td>5</td>
<td>14.7</td>
<td>6</td>
</tr>
<tr>
<td>Rescue tow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did not finish</td>
<td>1</td>
<td>2.1</td>
<td>1</td>
<td>2.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Poor</td>
<td>6</td>
<td>12.8</td>
<td>0</td>
<td>0.0</td>
<td>6</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>27</td>
<td>57.4</td>
<td>10</td>
<td>29.4</td>
<td>37</td>
</tr>
<tr>
<td>Good</td>
<td>11</td>
<td>23.4</td>
<td>11</td>
<td>32.4</td>
<td>22</td>
</tr>
<tr>
<td>Excellent</td>
<td>2</td>
<td>4.3</td>
<td>12</td>
<td>35.3</td>
<td>14</td>
</tr>
</tbody>
</table>

[378]
Norwegian Peoples Aid (2007). Annual drowning statistics for Norway
Quan L., Cummings P., (2003). Characteristics of drowning by different age groups. *Inj Prevention, 9*(2), 163-166

---

**Movement Economy in Breaststroke Swimming: A Survival Perspective**

Stallman R.K., Major J., Hemmer S., Haavaag G.

*The Norwegian School of Sport Science*

When adopting a head up position in breaststroke the center of gravity is displaced backward, farther from the center of buoyancy. This causes a tendency for the legs to sink, increasing the angle of the body with the horizontal plane and concurrently, resistance. Increased resistance theoretically reduces survival possibilities. The purpose of this study was to quantify the difference in energy expenditure for breaststroke with the head held constantly above the surface and for breaststroke performed with normal breathing. Classic Douglas bag respitometry was used. During submaximal swimming, the volume of oxygen uptake was significantly higher when swimming with the face constantly above the surface than with normal breathing. Both pulse rate and blood lactate levels were also significantly higher when swimming "head up".

**Key words: breaststroke, movement economy, survival**

**INTRODUCTION**

The goals of swimming instruction are numerous but the preservation of life should be common to all programs. Historically, attempts have been made to justify one swimming technique above others, both as the first to be learned and as the most important one. It is well known that North America has a long tradition of teaching crawl early if not first, and that Europeans generally favor breaststroke. It has been argued that breaststroke is the easiest stroke to swim with the head up for those who prefer not to place the face in the water. While this may in some ways be true, it is irrelevant and in many ways contradicts the goals of water safety.

Swimming educators have long focused on the necessity of breath holding/breath control, buoyancy control, orientation, balance and rotation in the teaching of swimming. The 19th century produced the concept of "watermanship" often described as the all around aquatic movement development needed for survival (Sinclair & Henry, 1893, Thomas, 1904). These same authors also used the expressions "fancy swimming" and "scientific swimming" referring to the ability to move in the water in harmony with the powers of nature rather than trying to overcome them. Lanoe (1963) and Whiting, (1971) define a swimmer as one who can cope with an unexpected submersion. Modern aquatic professionals emphasize a thorough aquatic experience relating the characteristics of the water to our bodies (Skullberg, 1985, Wilke, 2007), and a movement repertoire which permits almost any movement in any direction at any time. This reminds us of the unlimited demands and solutions of the synchronized swimmer or water polo player. Cureton (1943) and the USA Navy (1944) emphasized that an unlimited number of dangers requires an unlimited number of solutions. Recently the expression watermanship has been modernized to "aquatic competence" (Langendorfer & Bruya, 1995).

To advocate swimming breaststroke with the head up or to choose breaststroke as the easiest way to swim with the head up for those who do not like the water, is to negate virtually all of the goals of aquatic professionals with regard to water safety – drowning prevention. It is beyond discussion that such persons are more poorly equipped to cope with an involuntary submersion (Stallman, et al, 2008). While this is common sense, there remains a tendency to argue for breaststroke first for the very reasons cited above.

Before going on, the point must be made that this discussion is not about choosing between front crawl and breaststroke. Both are poorly suited as a first swimming technique. And neither is it a matter of choosing from among the four competitive techniques when so many others are available. However, in the context of this study, the purpose
was i) to emphasize the importance of effective breathing and breath control (in any stroke), and ii) to quantify the burden of added resistance when swimming breaststroke with the head continually above the surface, considered in a survival context.

Lastly the point must be made that survival is often a matter of efficiency of movement (or good technique). It has nothing to do with swimming fast, although efficient movement is also faster. At any given velocity, the more efficient the movements, the less energy they will require. The less energy required per unit time or distance, the longer one will be able to continue in any necessary pursuit of survival whether it be to swim or to remain in the same place. This is a point sadly overlooked by many swimming instructors, who often express the idea that good technique is only important for the competitive swimmer. Most aquatic experts (e.g. Cureton, 1943, The USA Navy, 1944, Lane, 1963, Wilke, 2007, Stallman, 2008) consider breathing in an optimal way, the most important aspect of efficient technique.

METHODS

While quantifying energy expenditure under the two conditions named above was the primary goal of the study, it was recognized that several factors might influence it. Factors considered possible confounders were: skill level, buoyancy, endurance, drag characteristics and motivation. From 40 volunteers, 20 were selected (12 male, 8 female) to give a broad, representative sample with relation to buoyancy and ankle drag. This would reduce any bias because of these two factors. The subjects were university physical education students, average age 26.1 (range 19.5-35.0).

Buoyancy was determined by hydrostatic weighing as described by Katch et al. (1967). As function was of greatest interest, weight at both full inspiration and full expiration was recorded uncorrected for trapped air spaces and residual volume. Body density as determined by Brozek et al. (1963) was calculated but not included in the study. The term functional buoyancy (Stallman, 1971) is used for the uncorrected values. Ankle drag was measured as described by Cureton (1943). The subject adopted a stretched prone position, arms forward and together, with full inspiration. A Salter spring scale registered the weight of the ankles resting on a horizontal rod just below the surface, heels under water. Skill level was defined by a composite of two values: the number of strokes required to swim 25m (as few as possible) and the fastest time possible for 25m. Twenty five meters was chosen to minimize the influence of endurance and to maximize the influence of technical skill. All trials were repeated 3 times and the best performance was used in the analysis.

Energy cost was measured by classical Douglas Bag respirometry while swimming in a flume. The sub-maximal velocity of 0.5 m s\(^{-1}\) was used for all subjects. If this velocity resulted in unusually high levels of plasma lactate, the subject was eliminated. Given that these were physical education students, few were eliminated for this reason. The subjects swam approximately 10 min. unhindered to reach a steady state. They were able to measure in spite of the significant differences. The lack of functional buoyancy and either swim to exhaustion or VO\(_2\) for either technique was only important for the competitive swimmer. Most aquatic experts (e.g. Cureton, 1943, The USA Navy, 1944, Lane, 1963, Wilke, 2007, Stallman, 2008) consider breathing in an optimal way, the most important aspect of efficient technique.

Table 1 Comparison of head up to normal breaststroke breathing technique

<table>
<thead>
<tr>
<th>Technique</th>
<th>VO(_2)</th>
<th>HR</th>
<th>La</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal breathing</td>
<td>X = 84.6 ml/m (SD=19.6, range = 59.3 – 132.7)</td>
<td>X = 135</td>
<td>X = 3.9 mmol/l</td>
</tr>
<tr>
<td>Head always up</td>
<td>X = 90.6 ml/m (SD=20.7, range = 64.0 – 140.2 (p&lt;0.001)</td>
<td>X = 147</td>
<td>X = 5.4 mmol/l (p&lt;0.05)</td>
</tr>
</tbody>
</table>

During swimming to exhaustion there was no significant difference between the two technical variations on swim time, nor on maximum HR. La levels however were significantly higher with head up (p< 0.05). With head up the average was 10.57mM (S = 1.90, range 7.35 to 14.39). With normal breathing, 9.37mM (S = 1.83, range 6.48 to 12.35, (p< 0.05).

There was no relationship between drag index, skill index, or functional buoyancy and either swim to exhaustion or VO2 for either technique.

RESULTS

When swimming with the face constantly above the surface, the oxygen uptake (VO\(_2\)) expressed in ml/meter was significantly higher than with normal breathing (p< -0.001, N=20). The average VO\(_2\) with head up was 90.6 ml/m (s=20.7, range 64.0 to 140.2) The average with normal breathing was 84.6 ml/m (s=19.6, range 59.3 to 132.7). HR during these trials was significantly higher with head up, HR = 135 vs HR = 147 (p = <0.01) and La levels were also significantly higher when swimming with the head up, La = 3.9 Mmol/l vs 5.4 Mmol/l.

Table 1 Comparison of head up to normal breaststroke breathing technique

During swimming to exhaustion there was no significant difference between the two technical variations on swim time, nor on maximum HR. La levels however were significantly higher with head up (p< 0.05).

With head up the average was 10.57mM (S = 1.90, range 7.35 to 14.39). With normal breathing, 9.37mM (S = 1.83, range 6.48 to 12.35, (p< 0.05).

There was no relationship between drag index, skill index, or functional buoyancy and either swim to exhaustion or VO2 for either technique.
not related to VO2, HR or La, thus the differences observed are most likely caused by a real increase in swimming body angle and increased resistance.

CONCLUSION
Significantly less energy is used when swimming breaststroke with the normal breathing pattern than with the head always up. This seems to justify the emphasis on mastering breathing techniques which most aquatic professionals would support. This is one example of how improved technique can have a real effect on potential survival in a life threatening situation.

REFERENCES

Cureton, T.K. (1943). Warfare Aquatics. Champaign, IL, Stipes Publishing


Post-exercise Hypotension and Blood Lipoprotein Changes following Swimming Exercise

Tanaka, H., Sommerlad, S.M., Renzi, C.P., Barnes, J.N., and Nualnim, N.

The University of Texas at Austin, USA

It is not known whether an acute bout of swimming exercise results in similar changes in risk factors for coronary heart disease. To address this question, a total of 20 apparently healthy subjects were studied. Each subject performed 3 experimental sessions (time control, running exercise, and swimming exercise) separated by at least one week. Brachial blood pressure did not change after the 3 sessions. However, both running and swimming produced significant decreases in ankle blood pressure compared with the time control (P<0.05). There were no significant changes in cholesterol or triglycerides after the swimming or running sessions. We concluded that postexercise responses in blood pressure and blood cholesterol do not appear to be different between running and swimming.

Key Words: blood pressure; cholesterol; acute exercise; aquatic exercise

INTRODUCTION
A single (acute) bout of exercise evokes changes in a variety of risk factors for cardiovascular disease (Thompson et al., 2001; Durstine et al., 2002; Henriksen, 2002; Williams et al., 2005). These acute effects of exercise dissipate rapidly before the next bout of physical activity is performed to constitute chronic exercise. However, the acute responses to an exercise bout and the chronic adaptations to exercise training should not be considered as separate entities (Thompson et al., 2001). Indeed, the magnitude of changes induced by chronic exercise training is highly comparable with those achieved acutely by one bout of exercise (Durstine et al., 2002). In a dietary intervention study, acute changes in blood pressure were predictive of chronic changes in blood pressure through a lifestyle modification (Chen et al., 2008).

Most of the acute exercise studies to date have focused on running and cycling. Reductions in blood pressure and triglycerides as well as increases in HDL-cholesterol have been reported following an acute bout of land-based exercise (Kenny & Seals, 1993; Durstine et al., 2002; Williams et al., 2005). It is not known, however, whether a single bout of swimming exercise results in similar changes in risk factors for cardiovascular disease. Although swimming is often assumed to produce health benefits similar to other physical activities that involve a large muscle mass, the results obtained in running and cycling cannot be extrapolated to swimming. Swimming is performed in a different medium and in a prone or supine rather than an upright posture, resulting in a zero-gravity situation. Indeed, swimmers are known to experience hemodynamic and metabolic responses and adaptations that are substantially different from land-based exercises such as runners and cyclists (Holmer et al., 1974; Tanaka et al., 1997; Parker Jones et al., 1999; Tanaka, 2009).

Accordingly, the aim of the present study was to determine the effect of an acute bout of swimming exercise on blood pressure and serum cholesterol concentrations. To address this aim, changes observed after swimming were compared with those recorded after running (land exercise control) and sitting (time control). We hypothesized that swimming would evoke changes in blood pressure and serum cholesterol that were comparable in magnitude to running.

METHODS
Subjects. A total of 20 young (29±2 years) apparently healthy sedentary and recreationally-active subjects were studied. None of the subjects was in a regular exercise training program. Potential subjects who could not
swim were excluded from the study. All subjects were non-smokers, non-obese, and free of overt cardiovascular or other chronic diseases as assessed by medical history. None of the subjects were taking cardiovascular-acting medications. The Human Research Committee reviewed and approved all procedures, and written informed consent was obtained from all subjects.

**Procedures.** Subjects came into the laboratory after 12 hours fasting. Each subject performed all 3 experimental sessions (time control, running exercise, and swimming exercise) randomized and separated by at least one week. During the time control sessions, subjects sat in a temperature-controlled laboratory room. The exercise protocol for the swimming and running sessions consisted of interval training exercises at an intensity of ~75% of heart rate reserve determined from the graded exercise test. The target heart rate during swimming was adjusted on the basis of the observation that maximal heart rate during swimming is ~10-15 bpm lower than that during running (Magel et al., 1975). The intervals were five 10-minute bouts of exercise with 1 minute of rest between each bout (for a total for 54 minutes). During pilot studies, many subjects expressed difficulty in swimming continuously for a prolonged period of time. This necessitated the implementation of the interval exercise format for the present study. All subjects wore a waterproof heart rate monitor to maintain the desired intensity of exercise as well as to document exercise heart rate. Subjects used the freestyle technique in an indoor swimming pool. During the running session, subjects ran on a treadmill in a temperature-controlled room. During both exercise sessions, subjects consumed a standard amount of water. We made an attempt to include a sham control session, in which subjects floated in the indoor swimming pool using a flotation device. But this session was abandoned due to excessive heat loss and the resultant reduction in body temperature.

Blood pressure was measured before each session noninvasively three times in the laboratory by the arm and ankle cuff techniques (Omron VP-2000, Bannockburn, IL) after the subject had been quietly lying in a supine position for at least 10-15 minutes. In order to eliminate investigator bias, arterial blood pressure was measured automatically with modified oscillometric pressure sensors incorporated in extremity cuffs. The validity and reliability of measuring ankle blood pressure using this automated device have previously been reported by our laboratory (Cortez-Cooper et al., 2003). The blood pressure measurements were repeated after exercise at 15-minute intervals to 60 minutes with the subject lying in the supine position. Brachial-ankle pulse wave velocity, a measure of arterial stiffness, was measured using the automatic device (Omron VP-2000). A blood sample was taken before and after the exercise protocols for later enzymatic analyses of plasma lipid and lipoprotein concentrations.

In order to provide insight into the physiological mechanisms underlying the hypothesized reductions in blood pressure, an echocardiogram using the ultrasound machine (Philips iE33, Bothel, WA) was performed to assess stroke volume and cardiac output. Stroke volume was calculated from the product of the cross-sectional area of the aortic orifice ($\pi*(aortic diameter/2)^2$) and the mean velocity time integral. Cardiac output was calculated from the product of stroke volume and heart rate recorded during the echocardiogram.

Based on the previous finding that the attenuation of heat loss was associated with the magnitude of postexercise hypotension (Franklin et al., 1993), core body temperature was measured during exercise through the use of the Core-Temp disposable temperature sensor and the data recorder (HQ, Palmeto, FL). Body fat percentage was measured non-invasively by dual energy X-ray absorptiometry (DEXA). Maximal oxygen consumption was measured using a metabolic cart during a modified-Bruce protocol.

**Statistical Analyses.** ANOVA and MANOVA with repeated measures were used for statistical analyses, and Newman-Keuls post-hoc tests were used to identify significant differences. All data are expressed as mean±SEM.

**RESULTS.** Baseline blood pressure values were not different between the time control, running and swimming sessions. Brachial blood pressure did not change significantly after all 3 sessions. Both running and swimming produced significant decreases in ankle mean blood pressure compared with the time control (P<0.05; Figure 1). Running also produced significant reductions in ankle systolic BP compared with the time control (P<0.05).

<table>
<thead>
<tr>
<th>Table 1. Echocardiographic and arterial stiffness measures.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
</tr>
<tr>
<td>TPR (U)</td>
</tr>
<tr>
<td>23.5±2.0</td>
</tr>
<tr>
<td>CO (l/min)</td>
</tr>
<tr>
<td>Stroke volume (ml)</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
</tr>
<tr>
<td>cPWV (cm/sec)</td>
</tr>
<tr>
<td>baPWV (cm/sec)</td>
</tr>
</tbody>
</table>

*P<0.05 from pre-exercise; †P<0.05 from control; CO=cardiac output; TPR=total peripheral resistance; cPWV=carotid-femoral pulse wave velocity; baPWV=brachial-ankle pulse wave velocity.

Baseline core temperature values were not different between the time control, running and swimming sessions. Maximum core temperature values recorded during running (38.6±0.1 °C) and swimming (38.0±0.2 °C) were significantly higher than those during time control (36.9±0.1 °C). Baseline lipid and lipoprotein values were not different between the time control, running, and swimming sessions (Table 2). There were no significant changes in total, HDL-, LDL-, VLDL-cholesterol, or triglycerides after the swimming or running session although HDL-cholesterol tended to increase after both swimming (10%) and running (12%) sessions.
Table 2. Plasma lipid and lipoprotein concentrations

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Running</th>
<th>Swimming</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Total C (mg/dl)</td>
<td>161±8</td>
<td>163±16</td>
<td>166±13</td>
</tr>
<tr>
<td>HDL-C (mg/dl)</td>
<td>58±5</td>
<td>58±7</td>
<td>59±6</td>
</tr>
<tr>
<td>LDL-C (mg/dl)</td>
<td>85±7</td>
<td>88±6</td>
<td>90±12</td>
</tr>
<tr>
<td>VLDL-C (mg/dl)</td>
<td>20±4</td>
<td>18±4</td>
<td>14±2</td>
</tr>
<tr>
<td>Triglyceride (mg/dl)</td>
<td>93±13</td>
<td>87±16</td>
<td>81±10</td>
</tr>
</tbody>
</table>

C=cholesterol

DISCUSSION

A number of studies have documented the changes in blood pressure and lipoproteins following acute bouts of land-based exercise, including walking, running, and cycling (Kenny & Seals, 1993; Durstine et al., 2002; Williams et al., 2005). However, little or no information is available regarding whether an acute bout of swimming would evoke changes in risk factors for cardiovascular disease. In order to properly address this question, we provided a land-based exercise control session in addition to the time control session. This allowed us to compare a water-based exercise with a land-based exercise. The results of the present study indicate that overall post-exercise responses were not different between running and swimming.

Swimming is an attractive form of exercise as it is easily accessible, inexpensive, and isometric (Tanaka, 2009). Because it is a non-weight-bearing activity due to the buoyancy provided by water, adverse effects on the musculo-skeletal system are rare (Becker & Cole, 1998). In marked contrast to the widespread popularity of swimming exercise, research focusing on swimming in general, and on swimming and risk factors for cardiovascular disease in particular, is rare (Tanaka, 2009). To the best of our knowledge, this is the first study to evaluate the post-exercise responses in blood pressure and lipoproteins following an acute bout of swimming.

An interesting and rather surprising finding of the present study was that post exercise hypotension was observed only in the leg (posterior tibialis artery) and no such changes were seen in the arm (brachial artery). It has been well established that mean arterial blood pressure is similar in all conduit arteries in the resting or basal condition (Kroeker & Wood, 1955). It is plausible that local vasodilation may be more pronounced in the lower limbs after exercise contributing to a reduction in ankle blood pressure. Indeed, the reduction in ankle MAP appears to be mediated by reductions in total peripheral resistance as cardiac output did not decrease and arterial stiffness, as assessed by pulse wave velocity, did not change.

On the other hand, it is not clear why a reduction in blood pressure was not observed in the brachial artery, especially in the running session. A lack of change in brachial blood pressure may be related to the exercise protocol (e.g., interval exercise mode, exercise intensity) and/or subject characteristics (e.g., young, normo-tensive). However, post exercise hypotension has been observed in young healthy normo-tensive populations (Kenny & Seals, 1993; Williams et al., 2005) similar to our subjects. Additionally, post-exercise hypotension does not seem dependent upon exercise intensity or exercise duration (Kenny & Seals, 1993), and interval exercise appears to be as effective as continuous exercise in eliciting post exercise hypotension (Wilcox et al., 1982). Further investigations involving hypertensive populations are warranted.

No changes in serum cholesterol concentrations were observed after either exercise mode though there was a tendency for HDL-cholesterol to increase. The results are generally consistent with the only other study in the literature that examined the effect of an acute bout of swimming exercise on blood lipids and lipoproteins (Ohkawa & Itoh, 1993). Ohkawa & Itoh, (1993) reported that HDL-cholesterol was significantly increased following an acute bout of swimming that included 30 minutes of warm-up swimming and a 100m swim time trial, whereas total cholesterol and LDL-cholesterol did not change in 10 male adolescent trained swimmers. It should be noted that in the present study, because a blood sample was obtained at only one point (60 minutes after exercise), there is a possibility that we may have missed significant changes that may have occurred before or after the blood sampling.

CONCLUSIONS

In summary, the results of the present study suggest that post exercise responses in blood pressure and blood cholesterol are not different between running and swimming and that both exercises induced significant post exercise hypotension in the leg but not in the arm.

REFERENCES


ACKNOWLEDGEMENT

This study is in part supported by the American Heart Association grant.
A Conceptual Paper on the Benefits of a Non-Governmental Search and Rescue Organization

Wengelin, M.1, de Wet, T.2

1Lund University, Department of Service Management, Helsingborg, Sweden
2National Lake Rescue Institute, Kampala, Uganda

This conceptual paper aims at discussing the characteristics of and differences between modern Western independent SAR institutions and the initiatives that have been taken in developing countries. It highlights the benefits of the non-governmental SAR organization, not only to provide search and rescue capacity, but also to be a vehicle of progress and change.

Key words: Search and rescue, safety at sea, poverty reduction

INTRODUCTION

Maritime Search and Rescue (SAR) is a state responsibility covered in international regulations such as the United Nations Convention on Law of the Sea (UNCLOS), the Safety of Life at Sea Convention (SOLAS) and the 1979 SAR Convention. UNCLOS for example, says that every State must require the master of a ship flying its flag to render assistance to any person found at sea in danger of being lost and to proceed to the rescue of persons in distress. Furthermore, it requires every coastal State to promote the establishment, operation and maintenance of an adequate and effective search and rescue service regarding safety on and over the sea and, where circumstances require, by way of mutual regional arrangements, to co-operate with neighbouring States for this purpose. In this way, UNCLOS provides the legal framework for action. However, the details of search and rescue obligations are to be found in various International Maritime Organization (IMO) Conventions.

The Search and Rescue (SAR) Convention of 1979 gives a clear definition of the term “rescue”. It involves not only “an operation to retrieve persons in distress, provide for their initial medical or other needs” but also to “deliver them to a place of safety”. This obligation to initiate action is activated once the responsible authorities of a State Party receive information that any person is, or appears to be, in distress at sea. It further states that, once a State Party has accepted responsibility to provide search and rescue services for a specified area, it is obliged to use search and rescue units and other available facilities for providing assistance to anyone in distress at sea, and that such assistance is to be provided “regardless of the nationality or status of such a person or the circumstances in which that person is found”.

The Safety of Life at Sea Convention (SOLAS) spells out the obligation on ships’ masters to render assistance. It says:

“The master of a ship at sea which is in a position to be able to provide assistance, on receiving a signal from any source that persons are in distress at sea is bound to proceed with all speed to their assistance, if possible informing them or the search and rescue service that the ship is doing so.”

Elsewhere, it stipulates that contracting Governments should undertake measures “to ensure that necessary arrangements are made for the rescue of persons in distress at sea around its coasts.”

In most of the developed world, with a high level of commercial traffic and leisure boating, this responsibility is handled by a combination of governmental organizations (Coast Guard, Naval units, Marine Police, Pilots etc) and non-governmental SAR specialists like the Royal National Lifeboat Institute (RNLI) of the Netherlands, The German Sea Rescue Society (DGzRS) and the Swedish Sea Rescue Society (SSRS). In the developing world this is not usually the case. The SAR is in many cases covered by a small and not always operative navy in combination with Coast Guard in areas with commercial traffic or areas with national strategic importance. In areas with a high density of tourism there might be found occasional SAR units specialized in taking care of tourism related accidents like scuba diving cases (Egypt, Red Sea) with a focus on medical evacuation. With the main part of the commercial traffic and tourism areas basically taken care of, there is one large group of seafarers left. Who is looking out for the individual, local, artisanal small-scale fisherman in the small boat, outtrigger or canoe?

“In some countries little consideration is given to SAR services for smallscale or artisanal fishermen due to insufficient awareness, lack of resources, lack of personnel knowledgeable about marine safety problems, lack of suitable craft, geographical considerations (e.g. numerous remote islands), inadequate technical land institutional infrastructure and other reasons. Because many fishermen are not politically powerful, and because there are no compelling statistics on losses, this issue is often overlooked though, more recently, fishermen have become more active in pushing such services or organizing them on their own.” The International Labor Organization (ILO 1999)

Competing with urgent issues such as combating diseases like AIDS and malaria, environmental problems, insufficient infrastructure and investments in the military due to internal or regional instability, the investments in a functional SAR network that reaches the outback fishing village is not high on the priority list. It is also not unusual that a most urgent need for and responsibility for SAR is a borderline problem somehow situated between different ministries, as is even the case in the international arena, a Department of Shipping (or the IMO) on the one hand and a Department of Fishing or Fishing Authority Organization on the other. It is furthermore common to categorize maritime search and rescue as being the most expensive method of saving lives at sea. This is, however, a very limited view on SAR and is usually put forward by non SAR professionals. SAR as an operation is the last resort; that is, carrying out search and rescue; to find and save a person in distress. Isolated, this can be seen as a costly exercise, and if focusing on high tech operations with helicopters and rescue cruisers it is certainly rather expensive. But there is another side of the coin. A SAR organization and especially non-governmental ones, works actively to avoid SAR operations through activities like education, information, training, and awareness campaigns. These are activities acknowledged as important for safety at sea (ibid), and should be an integrated part of a SAR system. A governmental SAR organization, where SAR usually is one of many tasks, can use the power of regulations when such are in place. A non-governmental organization works more closely with the community, often actively supported by the community where it is based. From this perspective SAR is more broadly defined; saving lives starts with knowledge and training, and the costs of a SAR organization are thus seen in another light. The specialized competence embedded in a SAR organization is beneficial through the entire chain of “saving lives”, from promoting life jackets to actually searching and rescuing.

The purposes of this paper are thus i) to highlight the role of the SAR organization (especially non-governmental) within the broader perspective of life saving and poverty reduction, ii) to describe the function of the typical non-governmental SAR organization, and iii) to describe the case study of the National Lake Rescue Institute (NLRI, the non-governmental SAR organization in Uganda).

METHODS

This paper is based on qualitative evaluation of an existing system of SAR organized by the National Lake Rescue Institute of Uganda (NLRI). It is also an evaluation of the operation of this organization as a Non-Governmental Organization as compared to SAR organizations in developed countries as well as governmental agencies. The material used
for this paper is a combination of operational experience from the East Africa region and field material derived from a safety at sea project initiated by the Lake Victoria Basin Commission. It is therefore based upon participatory observations, interviews, and in regard to the legislative background, a review of relevant rules and regulations. Case studies are presented of a SAR non-governmental organization from the developed world and one from the developing world.

DESCRIPTION OF SAR ORGANIZATIONS: FROM A DEVELOPED COUNTRY AND FROM A DEVELOPING COUNTRY

SAR operations are dependent on an equation based on survivability and time. Survivability is a function of local conditions such as water temperature, ability to swim, and the use of life saving equipment. This part of the equation thus provides us with an idea of how long a person in distress can survive. Time is a function of distance and speed of the rescuer. Put very simply the two are linked together; the longer the survivability the longer the time the rescue mission can take, either to cover longer distances or performing with lesser speed. On Lake Victoria, for example, with an average water temperature of 24-26 degrees centigrade, the problem of hypothermia is not an immediate concern. However, with limited swimming ability and experience, and the lack of personal flotation devices (life jackets) or other life saving devices, survivability is still low. Paired with an almost total lack of rescue capacity the situation becomes very serious.

A recent example from a ferry accident on Lake Victoria shows a less than 50% survivability even though many local fishermen came to the rescue - 26 of 50 passengers drowned. Here the SAR organization has a task to fill, decreasing the number of accidents and increasing the survivability when an accident does occur. Being in place with dedicated resources for search and rescue, it can also save lives when all the other initiatives have been fruitless.

SAR organizations are in many countries run as voluntary organizations, or as Non-Governmental Organizations (NGO's). A non-governmental SAR association can assume full responsibility for all SAR operations in coastal waters, with special emphasis on saving lives among the fishing population or leisure boaters (the non IMO fleet). Operating models for this are available in several countries around the world. The normal setup is a national association with a small coordinating head office, also responsible for fundraising. The SAR stations are locally administered units supported by the mother organization. There exist different examples of levels of governmental support and the share of voluntary involvement. In Norway the government supports the Norwegian Sea Rescue Society enabling it to run 24 permanently manned rescue stations. Another 14 rescue stations are manned with trained voluntary crews funded by memberships and donations. In Sweden, the Swedish Sea Rescue Society (SSRS), founded in 1907, and hence having celebrated it’s 100th anniversary in 2007, is one of the world’s leading independent SAR organizations. The SSRS operates approximately 64 rescue stations with about 140 rescue craft manned by some 1800 volunteers. All boats have been financed through private donations from individuals and organisations or through local fundraising. This model is extremely successful; taking care of more than 70% of all emergencies relayed through the Maritime Rescue Coordination Center (MRCC) in Gothenburg. The Swedish Sea Rescue Society receives no contributions at all from taxes or public funds, but is exempted from value added tax in regard to costs directly related to SAR operations. The examples above have one thing in common; the volunteer part of the work is performed by individuals with basically a stable income and a permanent living place. Their engagement replaces other leisure activities; instead of playing tennis you spend a couple of hours a week maintaining the rescue boat and training with the rest of the crew. Your professional life allows you to be on stand-by and to man the rescue boat within 15 minutes from a call-out. This can be compared to a “Volunteer Fire Brigade”. Furthermore, the potential “clients” have the financial strength to contribute to the organization through donations, gifts and/or membership.

In developing countries the living conditions are different, something that has to have an impact on how a rescue service is set up. A permanent and paid professional crew is required to ensure that there is a guaranteed core of competence. This will enable the SAR service to build competence, to maintain a high level of training and over time gain necessary experience. Complemented with a group of volunteers in training, to be used for activities in addition to the core SAR operations; this combination will create flexibility, redundancy, and a high state of preparedness.

In December 2006 the first volunteer rescue station in East Africa was launched as a part of the National Lake Rescue Institute (NLRI) in Uganda. As a true development station it went into operation on the border lake between Uganda and the Democratic Republic of Congo, Lake Albert. The station itself was built upon two 40 ft steel containers and the rescue craft a locally built wooden boat with a 25 hp outboard engine. The crew was initially all volunteer local fishermen trained by an international SAR volunteer from the Swedish Sea Rescue Society. Since its establishment the Lake Albert rescue station in Kaiso alone has saved more than 255 people in distress (no data exist however, for people saved by wearing an NLRI lifejacket). For the NLRI this establishment was a milestone. After nearly five years of struggle the first station outside its headquarters was at last in operation. Soon to follow was a partnership station with the Ugandan Wildlife Authority (UWA) in Queen Elisabeth National Park, where the equipment and training were provided by NLRI and the crew consisted of UWA park rangers. Since then more stations have followed, partnership stations as well as independent stations, and today more than 50 crew members have been trained towards an internationally accepted standard.

Putting the NLRI initiative in perspective it initially focused on Lake Victoria, where the number of casualties ranges up to an estimated 5000 per year. A trained crew, based on NLRI headquarter employed personnel, manned a small boat with a 25 hp outboard engine based just outside the Ugandan capital, Kampala. When a corporate social responsibility project, financed by a multinational oil company, was negotiated, the focus turned temporarily to Lake Albert. In this area oil prospecting was taking place and the oil company wanted to manifest its presence by contributing to the local community. Supporting the NLRI existing community based initiatives to establish a rescue service on that lake was one of the chosen projects. Financing the rescue station as such was the first step, recruiting and training a crew towards an international standard as first responders to maritime and environmental emergencies was the second, and finally sea safety awareness training and information, the third. The latter was performed with the station and the crew as a platform. In addition to the emergency response capability the local spin-off has since become obvious; life vest production and promotion, fisherman’s clubs, football tournaments, kids’ sea safety training and information etc. Without a sustainable financial solution it is unlikely that the development will continue and the death rate on the great lakes will continue to be appallingly high. Currently a project funded by the African Development Bank is attempting to find a private-public partnership solution to this very problem, but eventually it will depend on political will and involvement.

DISCUSSION

The case study above shows that local initiatives can make a difference. For commercial traffic, operating within the framework of IMO regulations, governmental organizations can enforce international safety regulations thus decreasing the accident rate and the need of SAR operations. Operating offshore furthermore increases the need of equipment suitable for the specific environment of the high seas, and this activity is more suitable for a governmental body. However, in other waters and for other categories of maritime activities, the non-governmental SAR organization is a vital complement; cooperating with (and within) the
local communities; providing education, training, and promoting the use of life saving equipment. It is also a cost effective solution to have efficient and dedicated local rescue units handling smaller operations in coastal areas or inland lakes, rather than large navy units or coast guard ships. A non-governmental organization also has the possibility to access external funds not available for nation states.

The establishment of local, community based, SAR units has been advocated before in different forums. A report for ILO (Ben-Yami 2000) points out that:

"The way to go, therefore, is by identification of local (including traditional) institutions and local leadership that can, with some outside support, organize their own SAR and storm-safety services as well as other related projects. In this respect, NGOs can play a very useful role."

Furthermore, a report of the risks and dangers in the small scale fishery by Tamil Nadu, looking into more than 2000 maritime incidents, concludes that:

"Existing community based search and rescue (SAR) efforts to be reviewed and to explore possibilities of capacity building and setting up of community based SAR units in village clusters. The Coast Guard cannot respond to every call for help from small boat fishermen" (Swamy 2009).

This however requires a basic organizational infrastructure and basic funds to create stability and sustainability. This is of national interest and thus in the interest of governments and should therefore be actively supported. It would be reasonable to assume that every dollar spent on a private, non-governmental SAR service would have at least a threefold multiplier effect on the initial spending due to the ability of an NGO to mobilize volunteers and raise other funds when properly established. Furthermore, in comparison with spending on governmental SAR capacity the NGO will not only provide SAR capacity but will also engage local communities, advocate safe practise, and work actively to decrease the number of SAR operations as such, something that a navy or a coast guard unit would have problems to achieve. SAR organization initiatives can arise from anywhere, through cooperatives, fishermen's organizations, maritime training centres or any source imaginable. Where it happens is not important, it is the engagement that matters and that should be supported when the idea and model is proven.

Even though there is little statistical information to be obtained on the matter, what there is indicates that the main category of fatalities on the seas around the world is related to artisanal fishing and small scale transports/ferries, mainly in coastal waters within 20 nautical miles (NM) from the shore. An estimated 24 000 lives are lost globally within this category according to an estimate by ILO (1999). This further strengthens the argument; that non-governmental SAR service is a good complement to governmental maritime units where the NGO shares the responsibility and caters for the safety of coastal activities such as fishing, and the governmental units operate on the high seas with large commercial traffic. Such a solution is beneficial for all parties; for the fishing communities engaging in their own safety, bringing down the rate of accidents and increasing the survivability of persons in distress, and for the governments solving a problem at a limited cost and being able to focus on other pressing issues.

The social impact of a SAR organization should not be underestimated. Around Lake Victoria it is estimated that every fisherman has up to seven (7) dependants. If 5000 lives are lost, theoretically another 35000 will lose their primary means of living. This will first of all affect women and children. Thus a SAR organization also has an impact on gender issues. Furthermore, the Lake Albert rescue station example has also shown that within the community, the rescue station as such has become a vehicle of progress. When providing a rural fishing com-

CONCLUSION

A non-governmental SAR organization is a multifaceted tool to handle several different problems. The primary contribution might be to facilitate a change of attitude vis-à-vis safety at sea issues, but the total effect will be broader than that. The social benefits, the community engagement, and the impact of less scattered families will be considerable. For a government it is a cost effective route to fulfilling the international obligations of the sea.

REFERENCES


Swamy, J (2009). Risks and dangers in the small scale fisheries of Tamil Nadu. SIFFS. Can be obtained at http://seasafetyouthasia.org

ACKNOWLEDGEMENTS:

The authors would like to thank Joanna McDonald and Sip Wiebenga for their important input and support, and making this paper possible to present.
Author Index
A
Abraldes, J.A. 42, 67, 77
Aggelousis, N. 89
Alberty, M. 115, 204
Alcaraz, P.E. 77
Aleixo, I. 291
Allen, J. S. III. 154
Alves, F.B. 194, 215, 217, 220, 374
Andre, F. 97
Andries Junior O. 47
Arellano, R. 45, 127, 130, 249
Avramidis, S. 354
Azevedo, S. 374
Azizi, M.H. 357
Baba, Y. 288
Bagheri, A.B. 357
Baik, W. 213
Baly, L. 50
Barbosa A.C. 47
Barbosa, T.M. 122, 137, 272, 312
Barla, C. 50
Barnes, J.N. 381
Becker, T.J. 314
Bednarik, J. 228
Beidaris, N. 242
Belvis, W.C. 317
Benavent, J. 119, 359
Bennett, E. 371
Berton, E. 50
Bideau, B. 52, 180
Bideau, N. 52
Blanksby, B.A. 105
Blixt, T. 329, 331
Böhnlein, S. 278
Boli, A. 89
Bonifazi, M. 84
Brito, C.A.F. 317
Buss, W. 283
Butterly, R. 354
Cala, A. 182
Cappozzo, A. 178
Carl, D.L. 247
Castro, F.A.S. 165, 307
Chavallard, F. 55, 206
Chaya, J.A. 333
Chong, L. 105
Chollet, D. 55, 74, 115, 117, 155, 157, 180, 204, 206, 286
Cid, M. 153
Colado, J.C. 119, 173, 359
Conway, P.P. 59
Corredíre, R. 157
Cortesi, M. 57, 84
Cosson, J.M. 59
Costa, L. 62
Costa, M.J. 137, 272, 312
Cruz, A.M. 312
Da Boit, M. 57
Dahl D. 377
Daly, D.J. 140, 157
De Aymerich, J. 359
De Jesus, K. 64
Dekerle, J. 196, 259
de la Fuente, B. 249
Denadai, B.S. 215
de Souza Castro, F.A. 257
de Wet, T. 384
Dickeron, T. 247
Diefenthaler, F. 257
Dietrich, G. 72
Djoumi, V. 67
Dominguez-Castells, R. 45
Donati, M. 178
Dopsaj, J.M. 245
Dopsaj, M. 69, 192, 222, 276
Douda, H. 252, 254, 299
Drosou, E. 254
E
Elipot M. 97
Elipot, M. 72
Espada, M.A. 194
Falco, S. 187
Falenchuk, O. 233
Fantozzi, S. 84
Femia, P. 127, 130
Fernandes, R.J. 42, 62, 64, 67, 74, 148, 157, 180, 204, 291
Ferragut, C. 67, 77
Figueiredo, P. 62, 64, 67, 157
Formosa, D.P. 124
Franken, M. 257
Fujinawa, O. 362
G
Garcia Massó, X. 119, 173, 359
Gatta, G. 57, 84, 178
Georgiou, Ch. 252
Gomes, L.E. 84
Gonçalves, P. 64, 148
González Frutos, P. 182
González, L.M. 119, 173, 359
Gourgoulis, V. 89, 252, 254, 296, 299
Gouveia, G. 50
Grelot, L. 50
Griffin, B. 247
H
Haljand R. 127
Hanai, A. 364
Hara, H. 213, 319
Hata, H. 226
Hauswirth, C. 196, 259
Havrihuk, R. 314, 321
Henderson, H. 97
Hendall, P. 72, 155, 196, 204, 259
Henrich, T.W. 199
Henriques, A. 374
Hinman, M.G. 305
Hiros, M. 213
Hirose, K. 362
Hohmann, A. 262, 278
Houel, N. 97
Houel, N. 72, 196, 259
Huang, Z. 201
Ichikawa, H. 341
Ike, T. 270
Invernizzi, P.L. 324, 326, 336, 339
Isaka, T. 185
Itami, T. 185
J
James, R. 142
Jarm, T. 168
Jigami, H. 362
Junge, M. 329, 331
Justham, L.M. 59
K
Kamiya, S. 132
Kaneda, K. 366
Kanefuku, J.Y. 165
Kaput, J. 228
Kaput, V. 168
Kasimatis, P. 89
Kawakami, T. 270
Kawamoto, K. 270
Kawano, H. 208
Keskinen, K.L. 74, 264
Keskinen, O.P. 264
Keys, M. 105
Kishimoto, T. 108
Kiuchi, H. 132
Kjendilie, P.L. 377
Klauck, J. 175
Kocherkin, A.B. 110
Kojima, K. 267
Kolmogorov, S.V. 110
Komar, J. 204
Kondo, Y. 362
Kurobe, K. 201
L
Langendorfer, S.J. 20, 333
La Torre, M. 86
Leko, G. 238
Lemaitre, F. 55, 206
Lemyre, P.-N. 22
Leprêtre, P.M. 204
Leslie, N. 247
Lex, H. 346
Lima, A.B. 42
Llewellyn, J.D. 354
Long, J. 354
Longo, S. 324, 326, 336, 339
Loss, J.F. 86
Lytle, A. 105
M
Macho, L. 62, 148, 291
Madera, J. 119, 173, 359
Maeda, S. 132
Mahiou, B. 52
Maia, J. 291
Manthra, V.R. 122
Mantripragada, N. 122
Marinho, D.A. 62, 122, 137, 272, 312
Marksteiner, A. 247
Marques-Aleixo, I. 157
Mason, B.R. 25, 124
Price, M.  142
Pinto, E.  312
Perisic, S.M.  245
Payton, C.J.  140, 142
Patti, F.  84
Paiva, A.  374
Özkol, Z.  276
Ozawa, G.  201
Oxford, S.  142
Osborough, C.D.  140
Ohgi, Y.  366
Ohba, M.  274
Ogita, F.  201
Ohba, M.  274
Ohtsuki, Y.  366
Ohishi, K.  185
Oikic T.  47
Okita, K.  288
Oliveira, C.  137
Oliveira, M.  317
Onodera, S.  208, 213, 319
Osborn, C.D.  140
Oxford, S.  142
Ozawa, G.  201
Olziol, Z.  276

Pais, J.H.  28, 154
Puel, F.  155
Q
Quan, L.  371
Queiroz, T.M.  312
Querido, A.  157
R
Rakotomanana, L.  52
Rama, L.  217, 374
Rao, G.  50
Razafimahery, F.  52
Reis, J.F.  215, 220
Reis, V.M.  272, 312
Rejman, M.  160
Renzi, C.P.  381
Ribeiro, J.  62
Rodriguez, F.A.  30
Rodriguez, N.  77
Roessler, H.  148
Roig, A.  163
Rosado, F.  374
Rouard, A.H.  33, 122
Roubou, A.  62, 122
Rozi, G.  222, 230
Rumyantseva, O.A.  110
S
Saitari, A.R.  357
Sánchez E.  45
Sato, D.  274, 288
Sato, S.  274
Sato, T.  185
Schack, T.  283, 346
Schmid, A.C.  283
Schnitzler, C.  115, 286
Scurati, R.  324, 326, 336, 339
Seidel, I.  262
Seifert, L.  35, 55, 74, 115, 117, 157, 180, 204, 286
Seki, K.  213
Sengoku, Y.  224
Shibata, Y.  319
Shimojo, H.  341
Shimoyama, Y.  185, 274, 288
Shiraki, T.  226
Siegel, A.  278
Silva, A.J.  62, 122, 137, 272, 312
Silva, R.  291
Silveira, R.P.  165
Sawhney, S.E.  59
Soares, S.  42, 67, 291
Sommerlad, S.M.  381
Soukop, G.J.  199
Stager, J.M.  267, 294, 305
Stallman, R.K.  329, 331, 377, 379
Strzalekiewicz, A.  160
Steffen, R.  302
Stem, L.  168
Strojnik, V.  168
Strumbelj, B.  228
Sugimoto, S.  108
T
Tachikawa, K.  362
Tadini, F.  326
Tago, T.  185
Taguchi, N.  201
Takagi, H.  100, 108, 132, 135, 170, 341
Takahara, T.  213
Takamato, N.  208
Takeda, T.  108, 135, 170, 224
Takise, S.  270
Tami, E.  57
Tanaka, C.  366
Tanaka, H.  381
Tanaka, T.  201
Tanner, D.A.  294
Teixeira, A.  217, 374
Teixeira, G.  137
Tella, V.  119, 173, 359
Thanopoulos, V.  222, 230, 276
Thomaidis, S.  254
Tokmakidis, S.P.  252, 254, 296, 299
Tomikawa, M.  226
Toubeis, A.G.  89, 252, 254, 296, 299
Tourino, C.  67
Toussaint, H.M.  115, 124, 346
Toussaint, J.F.  196, 259
Tsallis, G.  299
Tsukakimoto, S.  108, 170, 224, 341

U
Ungerechts, B.E.  175, 283, 302, 346
Usaj, A.  228

V
Vannozzi, G.  178
Vantore, J.  180, 204
Veiga, S.  162
Vennell, R.  145
Vescovi, J.D.  233
Vezos, N.  89
Vieluf, S.  346
Vila, H.  77
Vilas-Boas, J.P.  12, 42, 62, 64, 67, 74, 122, 148, 157, 180, 291
Vogel, K.  302
Vorontsov, A.R.  110

W
Wada, T.  185
Wakayoshi, K.  226
Watanabe, R.  319
Wells, G.D.  233
Wengelin, M.  384
Wertheimer, V.  238
West, A.A.  59
Wright, B.V.  305

Y
Yamamoto, N.  201
Yamamoto, T.  226
Yamatsu, K.  364
Yoshimura, Y.  270
Yoshioka, A.  208, 213, 319

Z
Zacca, R.  307
Zamparo, P.  57, 187
Zatoń, K.  349
Zoretić, D.  238
Biomechanics and Medicine in Swimming XI

Per-Ludvik Kjendlie, Robert Keig Stallman, Jan Cabri (eds)


Chapter 1. Invited Lectures
Chapter 2. Biomechanics
Chapter 3. Physiology and Bioenergetics
Chapter 4. Training and Performance
Chapter 5. Education, Advice and Biofeedback
Chapter 6. Medicine and Water Safety