MODERN PRINCIPLES OF TRAINING IN EXERGAMES FOR SEDENTARY SENIORS: REQUIREMENTS AND APPROACHES FOR SPORT AND EXERCISE SCIENCES

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Abstract

Reviews of the literature show that computer-animated games are ascribed a potential in motivating home-based exercise. In order to develop such “exergames” for sedentary seniors, three main tasks are identified and performed in this paper from a sport science point of view: First, a training target and physical exercises must be conceptualized, suitable for preventive training, for home-based execution and for integration into computer-animated games. Second, volume and intensity of the training have to be determined, including adaptations for different fitness levels and progression rules for continuous training. Third, criteria of movement quality should be defined for monitoring by technical sensors, recognizing beginning and end of series and decision-making on changes of training configuration on different time scales.

For each task, the literature is reviewed and the solution for the project at hand is described. The first and third task seem to be solved due to a comprehensive literature base and to technical development, respectively. On one hand, approaches to the second task can be based on well-accepted general principles of training. On the other hand, the status of underlying theories does not allow derivation of concrete values for volume and intensity. Therefore, specific trials are necessary.

Key words: ELDERLY, EXERGAME, PREVENTION, SERIOUS GAME, TRAINING PRINCIPLES

1 Introduction

Due to demographic development, every third person will be over 60 years old in 2035. This development will have enormous consequences for the health care system. While the benefits of health-oriented physical activity are well-recognized, problems arise with application of this knowledge: Seniors often lack choices for preventive exercise (Hinrichs & Brach, 2011), which is

- appropriate, individualized and scalable
- attractive to beginners and supports motivating for sustainers
- based on modern training principles
- within reach even with impaired mobility
Recent technical development in video tracking, sensors, and computer-animated games allow for home-based technical solutions which meet such requests for preventive exercise. In this context, the term “exergame” has been established to demonstrate the combination of “exercise” and “game” in this specific form of computer-based games. Harley and colleagues (2010) demonstrated, how Nintendo’s Wii in connection with a certain conception could be used to foster social processes in sheltered housing settings. Evaluations of the psycho-physical side of exergames, however, show an inconsistent picture. This might be due to the fact that using technology in addition to or instead of instructors or personal trainers implies special tasks for exercise physiology and sport science, which sometimes may not be solved in an optimal way. The aim of the present paper is

- to substantiate these problems from the perspective of sport science, and
- to introduce exemplarily an approach that was used to design an exergame system for seniors

This exergame system is part of a research project called “Motivotion60+”, which is included in the research and development framework of Ambient assisted living (AAL) of the German Federal Ministry of Education and Research (BMBF). “Motivotion60+” aims at integrating prevention into the everyday lives of Senior Citizens. The goal is to maintain and to improve the physical and mental fitness of the elderly so that they can live healthy and independently in their own homes as long as possible. As the name of the project indicates by the combination of the terms motivation and motion, this goal shall be achieved through the motivation of the elderly to healthy physical activity. In this context, the project partners rely on a combination of familiar items like TV, as well as innovative devices. Sensors, web-based platforms and modern means of communication are used to motivate the target audience to sporting activities in a fun way. Outdoor, endurance-oriented activities belong to this project as well as indoor game-based exercises. While we believe that the general aspects discussed in this paper apply to both parts, the concrete solutions described below focus on the indoor games.

In the following section, we summarize reviews of comparable exergames. Then we derive three main problems to be approached by sport science, in order to design the exergame system as mentioned above: (1) conception of exercises, (2) conception of training stimulus, and (3) quality control and rules of change. Sections three and four contain literature-based approaches to the first and second problem. Section five gives a sketch on a multi-level control circuit we use to manage the quality and rule of change problem.

2 Exergames and Sport science

Before results gained by scientific research are summarized, the concept of serious games in general and more specifically the concept of exergaming are presented.

A serious game is a game not considered as an end in itself as games usually are. Serious games still should be entertaining, but in addition they serve an explicit and carefully thought-out purpose and are not intended to be played primarily for entertainment (Wiemeyer, 2009). Exergames are a particular form of serious games. The term exergame indicates that physical exercise and gaming is combined. The objective of these kinds of games is to motivate people to participate in physical exercise. This objective is reached by hiding the tiresome side of working out with the fun side of playing. Therefore, the whole exercise process seems to be more attractive (Görgü et al., 2010).
The beginning of this new active world has primarily started with the release of the Nintendo Wii in 2006. The Nintendo Wii is usually described as the most well-known commercial example of an exergaming platform. A major reason for the recent rise in interest in exergaming is linked to the concern over the current high levels of obesity in Western society (especially in children). It is hoped that the fascination that video games have for children can be harnessed to engage children in greater physical activity (Sinclair et al., 2007, Hingston & Masek, 2007).

Summary from evaluation reviews

Due to the fact that the Nintendo Wii is commercially the most successful product, most scientific studies have been conducted to test the potential of this specific game concerning motivation for physical activity. The results gained by these scientific studies can be summarized as follows:

- Böhm, Hartmann and Böhm (2008) as well as Graves et al. (2007) show that playing different exergames uses significantly more energy than playing sedentary traditional computer games but not as much energy as playing the sport itself. The achieved intensity values can be classified as effective with reference to the minimum training volume (Wiemeyer, 2010).

- Positive effects of playing exergames on elementary perceptual-motor performance (Green & Bavelier, 2007), reaction time and balance performance (Wiemeyer, 2010) have also been detected.

The results gained by Kliem and Wiemeyer (2010) confirm that the Nintendo Wii may be a suitable medium of training balance in prevention and rehabilitation of adults. However, as the overall efficacy of game-based training is not as high as that of “real” training, they claim for a development of more variable game-based training programs. The findings gained by Brumels and colleagues (2008) also show differential results referring to the effects of game-based training. Nevertheless, their results underline the potential of exergames with reference to motivation. The majority of participants perceived the game-based training as less demanding as real exercises. Moreover, the participants playing exergames reported about more joy in comparison to the participants carrying out the real exercises.

Although this paper focuses on the possibility to increase the motivation to more physical activity it should be mentioned that next to the potential of exergames to improve motor skills and abilities, studies also show that the therapy of cancer, diabetes, asthma, burns, and brain injury can profit from the application of serious games (Wiemeyer, 2010). Moreover, Baranowski and colleagues (2008) prove that players of exergames can be positively influenced either in their eating behavior or in their physical activity or even in both. Lager and Bremerg’s (2007) literature review provides strong evidence that video and computer game playing in general has positive effects on spatial abilities, which are very important for problem solving. However, once more the authors criticize methodological deficits of many studies.

Conclusions from a sport science point of view

In general, authors of reviews seem to agree in ascribing exergames a large potential for motivation and support of healthy activities for different target groups. Beneath these encouraging results, another aspect is important for the design of the “Motivotion60+” exergame. Taking into account an exergame approach of “hiding the tiresome side” of exercise, it is not surprising if exergames fail to reach effective activity levels. Instead of
this “game-first” strategy, exercises could be prioritized as follows: defining goals, planning exercises and training parameters as in advanced training, but then integrating this into a computer-animated game and a “story”. A problem of this approach, however, could be the lack of a human instructor or trainer, who normally gives support and supervision to the athlete or client, and who not only designs plans on different time-scales, but also decides on short-term changes of the plan if necessary.

For the project at issue the decision was made to prioritize exercise in the sense of meeting modern training principles. On the other hand, concessions to motivation through games and stories were warranted as far as possible. From this basic conception, the following three tasks for sport science could be derived. They have to be solved within this project:

1. A conception of physical exercises has to be developed. Exercises should target on preventive training, be suitable for home-based training and for combination with computer-animated games.
2. Training parameters have to be determined in a dynamic way on the basis of training scientific principles. Users with different capabilities and fitness levels should be able to start exercising and individually increase training load without a trainer being present.
3. Criteria of movement quality have to be defined so that the quality can be monitored by technical sensors, the beginning and the end of series can be recognized and decisions can be made concerning changes of training configuration (i.e., advancement or fall-back) and to prevent that some user might trick the system (i.e., playing the game without performing the exercises correctly).

Specifying tasks from a sport science perspective does not mean that only sport scientists would deal with them. The tasks were worked on by an interdisciplinary team including game-designers, engineers and scientists. In the following three sections, snapshots of this work in progress are presented along the three tasks.

3 Conception of exercises and integration into computer-animated games

3.1 Rationale for the development of the virtual, indoor training program

A main target for the program development was to define relevant exercises for an older population as addressed in “Motivation60+". Among the multitude of optional exercise forms a limited subset had to be selected which was adequate and feasible for the addressees of “Motivation60+” and could be translated into the virtual training setting of the project.

As a first step we defined a training target which seemed feasible and had a substantial impact on quality of life and clinical prognosis in the target population. Based on the fact that fall risk is associated with aging with more than 30% of people over 65 years and 50% of people over 80 years suffering from a fall each year (O’Laughlin et al., 1993) we chose “fall prevention” as the training target for our exercise program.

Motor deficits such as lack of strength, balance and functional performances such as walking or stair climbing have been identified as dominant risk factors for falls (American Geriatrics Society et al., 2001). More recently, deficits in complex, motor-cognitive skills have been shown to increase risk of falling in epidemiological studies. Cognitive deficits as well as motor deficits including falls represent the dominant predictor for loss of independence (Lord, 1994). Loss of independence represents the most feared issue in older people's life and is more frequently rated as accidents,
robbery, or even death (Salked et al., 2000). Even when autonomy is not at stake, the sequelae of falls severely affect older people as functional (ADL) and instrumental Activities of daily living (IADL) will be lost permanently in up 50% of fallers after severe falls. (Lin & Chang, 2004). Apart from somatic traumata a large number of persons who suffer a fall, develop psychological trauma with respect to fear of falling associated with restriction of physical activity, increasing isolation and decreasing quality of life (Bruce et al., 2002; Kannus et al., 1999; Stel et al., 2004).

A large number of well-designed, randomized interventional studies (RCTs) with standardized training interventions have been performed in the last 15 years (Gillespie et al., 2003; Gillespie, 2009). As a stand alone intervention or within multiple intervention strategies, exercise training had turned out to be the most frequent study intervention to prevent falls in a non-selected population. Intervention effects depend on the preselection of the study population, intensity and standardization of training and other methodological issues with training effects reaching up to a reduction of falls/near falls by 45% (Wolf et al., 2003) with an average of 15% in non-specific training programs and 25% in more specific training programs (Gillespie et al., 2003).

Based on results of systematic reviews and systematic meta-analysis, the use of progressive resistance training, even more the use of progressive functional training with focus on static and dynamic balance and functional training of motor performances such as climbing seems to be most effective. In contrast mere endurance training or walking sessions such as Nordic Walking did not show a significant reduction in risk of falling (Sherrington et al., 2008; Chang et al., 2004; Gardner et al., 2000). Recently, complex training tasks including motor as well as cognitive challenges such as dual tasking or dance exercises had been included in interventional fall prevention studies or studies on risk factors for falls (Trombetti et al., 2011; Schwenk et al., 2010).

The selection of training exercises in the present project “Motivotion60+” was based on the results stated above. Progressive training adjusted for individual performance levels of strength, dynamic balance and complex exercises with both cognitive and motor challenges were suggested as the core of training exercises.

In a second step we adjusted the selected exercise to the requests of the technical partners. Adjustments relate to the introduction of the exercises into the “story” of the training program (the flight of the participant to major capitals and related “typical” training tasks), the adjustments to technical request and the organization and rating of the training sessions according to different performance levels. Adjustments had been a compromise between optimizing physiological training effects and translation into motivating, virtual training locations.

3.2 Overview of exercise mini-games

The story of the “Motivotion60+” game is a journey to world-famous cities. Most of the seniors travel for private purposes (Gallup Organization, 2011). For persons with diminished capabilities for trips, continuing interests in foreign countries or cities can be assumed. Each city is represented by a “typical”, well-known scene (e.g. Venice: pigeons on Saint Mark’s Square) or activity (e.g. Rio de Janeiro: soccer). The scene serves as framework for an exercise mini-game according to the conception presented above.

In total, seven mini-games were developed. They can be divided into three different categories: strength exercises, balance and stabilization exercises and complex exercises. In addition, knowledge facts on cities and countries are presented during each mini-game. Later, the user can test his or her knowledge through a quiz. The airplane
flights between locations are also embedded into an exercise mini-game: while the plane is steered by whole body movements (lateral bending of the trunk, lifting the arms) with additional balance requirements (foot positions), collisions with birds or mountains should be avoided. Table 1 gives an overview of the seven mini-games according to the three categories, Figure 1 presents screen-shots.

Table 1: Overview of the seven mini-games according to the three categories.

<table>
<thead>
<tr>
<th>Venue</th>
<th>Plane</th>
<th>Rome</th>
<th>Paris</th>
<th>Paris</th>
<th>Venice</th>
<th>Rio</th>
<th>Athens</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Game story</strong></td>
<td>Steering the plane</td>
<td>Riding a chariot in the Colosseum chariot race</td>
<td>Climbing the tower of Notre Dame</td>
<td>Ringing the bell of Notre Dame</td>
<td>Chasing pigeons on Saint Mark’s Square</td>
<td>Keeping the goal in the soccer stadium</td>
<td>Dancing Sirtaki</td>
</tr>
<tr>
<td><strong>Exercise category</strong></td>
<td>Balance and stabilization</td>
<td>Balance and stabilization</td>
<td>Strength</td>
<td>Strength</td>
<td>Complex exercises</td>
<td>Complex exercises</td>
<td>Complex exercises</td>
</tr>
<tr>
<td><strong>Exercise description</strong></td>
<td>Lateral bends, different foot positions, arms straight lateral</td>
<td>Lateral bends, different foot positions</td>
<td>Marching</td>
<td>Squat</td>
<td>Abduction standing on one leg</td>
<td>Sidesteps and lateral bends, reaction and time-to-contact</td>
<td>Dancing, with single stand phases</td>
</tr>
</tbody>
</table>

Exemplary, the mini-game “Chariot Race” with its basic idea and its training components is presented. The “Chariot Race” in the Colosseum of ancient Rome belongs to the balance and stabilization exercises. The exercise consists of steering the chariot through the Colosseum by leaning the upper part of the body to one or the other side. In addition, the player is challenged to collect coins that are lying on the ground by running over them, and avoid collisions with rivals. The speed of the chariot can be influenced by lifting one arm. There are several parameters, which are used to adopt this exergame to fitness and capabilities of the user, and also to define progression in the sense of exercise physiology principles. The underlying exercise is assigned to the balance category, which belongs to coordination as motor capability. Unlike endurance or strength training, the training parameters cannot be measured in SI units of work (volume) and power (intensity). Thus, definitions should correspond to the idea of extent and difficulty of exercising:

1. Therefore, exercise intensity is defined by task difficulty, which itself is determined by three foot positions: hip-wide stance, semi-tandem stance and one-leg stance.

2. Exercise volume is determined by the range of the lateral bending motion used to steer the chariot. Thus, a decrease in steering sensitivity—e.g., more bending is required for a lane change during an overtake maneuver—is utilized to increase exercise volume.

3. Additional cognitive and sensori-motor challenges are controlled through the number of coins, i.e. chances to receive extra game points.

Whereas this exercise generally trains motor skills like posture control, it also imposes requirements to cognitive skills. During the game, the player has to react appropriately according to different situations (changes in the race course, turns, coins, rivals). Considering the coordinative skills according to Roth (2003), this exercise requires vestibular, kinesthetic and visual information and creates time, situation and complexity pressure.
4 Parameters for adaption and progression of exercise requirements

The second task identified in the introduction is to determine start configurations of exercises and to assure training progression. In common training situations, a human instructor or trainer is responsible for planning and controlling the training process (Schnabel, Harre & Krug, 2008). The system of "Motivotion60+" replaces the role of a trainer. Thus, the training configuration of the different mini-games must be determined in advance. In the first subsection (4.1), helpful advice is searched in the literature. Afterwards (4.2), conclusions for the project are presented.

4.1 From general principles of training to concrete exercise configuration

Weight training can be used to exemplify the need for exercise configuration: How many repetitions in what velocity should be conducted? How much extra weight is to be moved over what distance? How many breaks are between the sets and how long should they be? In summary, the training configuration describes the training stimulus, which is ascribed to cause the favored biological adaptation, i.e. strength development. There is a large number of different training principles in exercise physiology, describing training methods and recommendations for dynamics of training configuration. They do not give any explicit instructions on how to organize the training process, but can be considered as general orientation according to three categories (Olivier, Marshall & Büsch, 2008, Tab. 9): (1) training principles derived from pedagogy, (2) general training principles related to performance development, and (3) specific training principles related to a certain (a) capability, (b) target group or (c) discipline. The following paragraphs contain principles that are considered important for the training configuration of the “Motivotion60+” mini-games.
The most important general principle is that the training stimulus must be above threshold so that biological adaptation can be achieved (Weinek, 2010). Furthermore, a training process should always be individualized, because a training stimulus can be adequate for one person and at the same time may be not challenging enough for another person. According to comparable principles developed by Harre, Richter and Ritter (1973), Letzelter (1978) and Schnabel et al. (2003), it is absolutely necessary that the loading increases systematically. Even if there exist numerous possibilities of how to increase the loading of someone’s training, this article limits itself to explain the principles used for the training configuration of the “Motivotion60+” mini-games. One possibility to increase the loading is by increasing volume and intensity of an exercise. In training configurations for children or beginners the loading is normally increased by increasing the volume first followed by intensity. Another possibility is to increase the demands on movement coordination. With regard to the question on how much the load is increased, it can either be increased gradually or variably. In training configurations for children or beginners the loading usually increases gradually.

The training configuration of the mini-games had to be established in advance. Thus, it was necessary to define exactly when and how to increase the training load. Therefore, we conducted a literature research using “Sportdiscus”, the largest literature database in sport science. The search terms periodization, strength training, training volume and training intensity were used. Most of the resulting papers and articles present an overview of this topic in the area of high-performance sport, whereas there was no result focusing on the training of the elderly which is of interest here.

4.2 Conclusions for the adoption of training principles

With reference to the training configuration rules found in the literature, it becomes clear that there are generally accepted and useful training principles. However, our literature search could not yield papers with concrete configurations suitable for the purpose of home-based training with the elderly. Concrete specifications of training parameters were exemplarily told by Stone (1981) and Fleck (1999a, 1999b) for high-performance sports. Loads between 1RM and 10RM (xRM being the repetition maximum load for a certain exercise which the athlete is able to perform x times but not x+1 times) clearly are neither suitable nor safe for health-oriented home-based training in the elderly (without instructor present). The idea of simply scaling down the load should not be expected to be helpful in adapting the configuration to the target group, because the other parameters would be influenced.

Considering the broad spectrum of capabilities in aged users starting the exergame, and considering adaptations by regular exercise, a very flexible system of training configurations with rules for upgrades but also for downgrades on different time scales is essential for successful training. Due to the research deficits mentioned above, we have determined a provisional training configuration in our system and will adjust it afterwards according to the results gained in the first user study. In addition, the system should generally be open to subsequent adaptations and future upgrades. This corresponds to the open system approach.

While training dynamics are thus left to further development, we were able to define an overall training volume by taking §20 SGV V (Fünftes Sozialgesetzbuch, Section 20 of Book V of the German Social Welfare Code) as a basis. This section allows health insurances to remunerate course fees, if the participant exercises ten weeks of 60 minutes each in a course of defined quality. Consequently, we set this value as an overall goal and used quality-assured exercise time as “currency” to measure exercise volume. Several regulations were defined:
With regard to the conception of mini-games, the user has to play at least 20 minutes in each category.

Only movements corresponding to established characteristics of training quality are considered as training time.

Furthermore, we considered a minimum of 30 or 60 seconds, respectively, of uninterrupted playing as countable for categorial and overall exercise volume. This regulation is necessary to achieve a training stimulus which is above threshold.

Beneath these few regulations, individual freedom of choice to play the mini-games of individual preference, exercise variety and an ensured minimum degree of effective training are clearly the advantages of this program over group training.

5 Control of movement quality and decisions on training progression

The system should be able not only to set up and to adapt targets, but also to control what the user really does. Therefore, a multi-level control circuit was conceptualized. It is displayed in figure 2. It consists of three parts: (1) a three level exercise configuration unit for defining a target, (2) a control unit to measure and to evaluate actual movements and game performance, and (3) a set of rules to decide on changes of configuration.

Figure 2. Multi-level control circuit for exercise configuration and quality control.
The exercise configuration unit is used to define the target exercise in three aspects:

- **Daily fitness control:** In the first frame individual intensity is adjusted by ad hoc-changes during a play-through. These are small adaptions to the user’s daily conditions and efforts. For example ad hoc-changes in the mini-game “Chariot race” are produced by increasing or reducing the number of coins and rivals.

- **Exercise volume:** The second frame adjusts the volume of an exercise within the same game level when starting a new play-through. Increasing volume means increasing the number of movements or increasing the range of motion within a single movement. In the “Chariot race”, the range of motion is increased by a less steering sensitivity. This means that the user has to conduct a stronger lateral bend in order to steer the chariot through the Colosseum.

- **Exercise intensity:** If the exercise was performed successfully with maximal volume, the level of difficulty is increased by a new game level with higher intensity, e.g. a more demanding foot position in “Chariot race”, a higher movement speed in strength exercise.

A Kinect video-tracking system (Microsoft) is used to record data on actual performance. The actual game evaluation unit is used to analyze these data with regard to four tasks:

- Start, end and type of exercise is identified.
- Uninterrupted exercise time, total time per exercise, overall exercise time are recorded for purposes of training plan.
- Exercise quality is evaluated by predefined parameters. Data on movement correctness can be used to give feedback to the user.
- Game-related data is recorded (e.g. number of coins collected, number of birds eluded) in order to count successes, points and other rewards.

Comparing target exercise with actual movements, the base of rules is used to assure three features in order to make the system adaptive and flexible:

- In case of overtaxing the user automatically falls back to a lower level (“fallback”). For example when the user commits too many mistakes, that is in the case of “Chariot race” to miss too many coins or collide with too many rivals.
- In addition, the user has always the possibility to go back to a lower level by using the “smoother“- button.
- When the number of correct exercise units (exercise time) necessary for a configuration upgrade is reached, progress in the training plan (see configuration unit) is initiated.

### 6 Discussion

Within the research and development project “Motivotion60+”, an exergame system for elderly people was conceptualized. The technological implementation is appropriately done and significantly improved through Microsoft Kinect. Meanwhile, two prototypes are tested in a feasibility trial.

With regard to the theoretical design we can conclude, that “Motivotion60+” is still behind due to the insufficient theoretical knowledge in training science. While general principles are widely accepted, we did not find rules how to define concrete values for training progression with the target group. As a consequence, training parameters have
to be substantiated through the experiences of the feasibility and acceptance trials. For this purpose, an authoring system (StoryTec) will be used. Changes in volume and intensity values, but also position coordinates and angles used to define movement quality will be easily changeable.

Considering the large differences in fitness status found in seniors, maybe automatic rules of training progression will be insufficient even after further research. If manual intervention will be necessary in the future, the open system approach used in design of this exergame could also be helpful in later use cases: Exercise experts or even geriatric carers could adjust and scale the system for target subgroups or individuals using the authoring system. Again, hints and directions for further research & development steps can be expected from user trials, but also from the scientific community.

References


