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LITERATURE REVIEW

ISOKINETIC TRUNK STRENGTH, VALIDITY, RELIABILITY, NORMATIVE DATA AND RELATION TO PHYSICAL PERFORMANCE AND LOW BACK PAIN: A REVIEW OF THE LITERATURE

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ABSTRACT

Background: Isokinetic testing of the trunk is ubiquitous in the literature and with training, however, there is a lack of normative data for adolescents and adult athletes.

Purpose: The purpose of the current review is to present and summarize data about isokinetic trunk strength assessment relative to young, adolescent and adult athletes. Testing position variations, reliability values by age groups, utilization of strength measures and normative data by age groups have been discussed. The information presented within this review are of practical importance for assessment of isokinetic trunk strength to appraise the athlete's current strength level and provide suitable conditioning training program.

Study design: Literature review

Methods: NCBI-PubMed, Web of Science, and SPORTDiscus were searched to identify relevant correlation and intervention studies/trials related to isokinetic testing of the trunk. Forty-two studies meeting the inclusion criteria were included in this literature review.

Evidence synthesis: The validity of isokinetic trunk measures (i.e. peak torque; flexion/extension ratios) can be affected by a number of factors including whether the individual is tested in seated or standing position, which can alter the muscle length–tension relationship. Reliability is excellent for some strength measures and moderate to high for muscle endurance. Extension and concentric measures tend to have better reliability than flexion and eccentric measures respectively, while females show typically higher reliability scores than men due to the difficulty in controlling men's body position when testing. Normative data for various populations are provided.

Conclusions: Muscle assessment methods using an isokinetic dynamometer are considered reliable with high correlations to peak strength values and flexor/extensor ratios over age groups. However, caution should be exercised when interpreting position-specific isokinetic test results that measure trunk flexion (standing vs seated position). Still, there are indications that low-velocity movements are more reliable for measuring trunk strength. In adolescence, boys appear stronger than girls, with higher values for trunk extensors. Trunk flexors and extensors ratios decrease with growth. Data of isokinetic trunk muscle performance seems to be correlated not only to anthropometric parameters but also to sports discipline and training volume. The effects of sport on the muscular strength of the trunk may have both a preventive factor and a possible risk factor for low back pain. There is evidence for an association between high physical workloads and back injury.

Level of Evidence: 5

Key words: core, endurance, isokinetic reproducibility, trunk strength testing, sport

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INTRODUCTION

Trunk flexion is ubiquitous in daily activities, such as walking or sit-to-stand,[1] and in different sports performance actions, such as overhead throwing[2,3] or hitting a ball.[4] Authors have demonstrated the importance of trunk strength for preventing injuries in the spine[5,6] and knee,[7,8] such as the low back pain and anterior cruciate ligament injuries that frequently occur in sports and the workplace.[9,10]

Strength testing of the trunk muscles plays an important role in functional evaluation. Initial discussion on trunk strength testing dates back to the 1940s and since then numerous testing procedures have been introduced into clinical practice. One of these procedures is isokinetic testing. Although isokinetic dynamometers are commonly used in clinical practice for testing of the extremities, only a few findings regarding the reproducibility of trunk strength testing exist.[11] Isokinetic measurements are based on the principle of testing strength capacity under constant rotational or linear motion velocities and are considered the 'gold standard' for assessing strength capacity.[12] Current dynamometers are capable of measuring isometric, concentric and eccentric contraction modes for clinical, performance and scientific applications. Isokinetic dynamometry is a well-accepted tool for assessing strength of the upper and lower extremities as well as trunk muscles, and isokinetic strength testing is a useful approach to assess trunk extension and flexion in healthy individuals as well as in patients with low back pain.[5] In order to assess isokinetic trunk strength, many different devices have been developed for standing[13] or sitting positions.[14] Isokinetic (peak torque (PT) and work (W)) and isometric parameters (PT and rate of force development or rate of torque development) can be assessed. Furthermore, isokinetic measurements can be used to identify strength deficits in individuals with and without pathologies. In addition, the evaluation of the outcomes of preventive and rehabilitative interventions is important. The measurement of PT is commonly used as a proxy measurement of trunk strength and serves as a valid outcome parameter for reporting trunk extension and flexion strength in both healthy subjects and patients with low back pain. Moreover, it is used to define deficits in specific pathologies, as well as to evaluate effectiveness of training and therapy.[5] Strength is essential for stability (ability to compensate for perturbations to balance) in healthy individuals and those with back conditions (i.e. low back pain [LBP]) and performance of the core (trunk).[15] Research on isokinetic assessments of lateral flexion and rotation are quite rare and reproducibility in these two planes (lateral flexion/rotation) has not been sufficiently analyzed.[5]

The functional applicability of isokinetic measurement still remains questionable. Some scientists agree that isokinetic movements are "unnatural" and the motion involved is not related to that which occurs during sporting performance".[16] In addition, it has to be emphasized that what is being measured is not internal muscle tension but the torque/force output of complex muscle systems especially when assessing the spine. Isokinetic dynamometry is considered a valid and reliable device used to determine the force, or torque, generated by a muscle group for a specific action,[13] having good-to-excellent reliability. Isokinetic dynamometry, however, is not universally accessible and is rarely used clinically owing to its high cost, requirement for considerable user expertise, and protracted testing time.[17]

There is great benefit in using trunk isokinetic dynamometry to reliably assess strength parameters.[13,18] There is a lack of normative data of trunk flexors and extensors muscle strength in the literature. Particularly, there is a lack of normative data from asymptomatic adolescent and adult athletes. Unlike the arms and legs that can compare or normalize the strength of a limb to the contralateral limb, the trunk does not present this possibility. In this way, the comparison of the trunk strength of an individual always will need to be compared with population normative data or parameters of normality.[19]

The purpose of the current review is to present and summarize data about isokinetic trunk strength assessment relative to young (children), adolescent and adult athletes. Testing position variations, reliability values by age groups, utilization of strength measures and normative data by age groups have been discussed. The information presented within this review are of practical importance for assessment of isokinetic strength of trunk and conditioning professionals in appraising their athlete's current strength level and providing accurate conditioning training programs. Typically, isokinetic trunk assessments examine joint range of motion, muscular strength, power and balance between agonists and antagonists muscles, as all of these variables are considered crucial for optimal performance whilst playing a role in reducing an athlete's risk of injury. Muscle strength ratios are commonly tested to describe unilateral antagonist to agonist strength properties, functionality and imbalances

METHODS

The present literature review was conducted in accordance with the recommendations of the "Preferred Reporting Items for Systematic Reviews and MetaAnalyses" (PRISMA).[20]

Literature Search

The literature review was performed with the databases of PubMed, Web of Science, and SPORTDiscus; for correlation and for intervention studies. The following search terms were included in search strategies: "isokinetic and trunk", "isokinetic and low back pain", isokinetic and trunk and healthy", "isokinetic and trunk and athletes", "isokinetic and trunk and adolescent", "isokinetic and trunk and therapy", "isokinetic and trunk and prevention", "isokinetic and trunk and training", "isokinetic and trunk and exercise", "isokinetic and trunk and validity", "peak torque and trunk", "peak torque and trunk and healthy", "peak torque and trunk and athletes", "peak torque and trunk and adolescent", "peak torque and trunk and prevention", "peak torque and trunk and training", "peak torque and trunk and exercise" and "peak torque and trunk and validity". By using the filter criteria of the respective databases, the search was limited to full-text availability, publication dates (2000 to 2018), humans, ages (i.e., 16-44 years), and English language. Further, the reference lists of the included studies as well as relevant review articles were screened for titles in order to identify additional suitable studies for inclusion.

RESULTS

The search strategy revealed 224 references among which 42 presented relevant isokinetic strength measures derived from testing of healthy subjects without pathologies, athletes and/or adolescents. Most frequently, data for trunk extension and flexion strength were evaluated with cross-sectional designs (31 papers for flexion/extension, three for rotation, and none for lateral flexion). Nine out of the 31 'sagittal' studies reported isokinetic measures for patients with low back pain (PLBP), 29 for healthy subjects/others and seven involved both healthy subjects and PLBP. Studies investigating prevention, therapy or training effects (eight total) or using isokinetics as an intervention were rare.

Results revealed that standing flexion elicited significantly greater PT, W and power (P) values than sitting, at both velocities tested, whereas no differences were noted in trunk extension. When testing sagittal plane trunk strength in the upright posture, Guilhem et al[13] found torque values ranging between 152 and 453 N.m in trunk extension, and between 99 and 263 N.m in trunk flexion, which is in accordance with the values reported for healthy subjects tested in similar conditions.[21] Previous studies demonstrated a 30% increase of flexor torque from supine to standing position, which is closer to the functional configuration of daily or sport tasks.[22] Moreover, the upright configuration has been shown to reduce the contribution of muscles crossing the hip joint, thus leading to lower torque variations compared to the supine position.[23]

In a recent review on pediatric strength testing, De Ste Croix[24] stated that test-retest-variability in isokinetic strength testing in children ranges between 5 and 10% regardless of joint tested. Furthermore, De Ste Croix[24] deduced in his review that extension movements were more reliable than flexion movements, concentric muscle action was more reliable than eccentric work and that reliability was reduced with increased testing velocity. With adolescents, Carvalho et al.[25] reported questionable as well as clinical acceptable to excellent reproducibility in adolescent basketball players for isokinetic strength testing (ICC: 0.72-0.99). Lindsay et al.[26] reported an acceptable reproducibility in the adolescent cohort with isokinetic trunk rotation and endurance at a testing velocity of 30°/s (ICC: 0.86-0.87). Müller et al.[11] found excellent reliability (0.91-0.94) with adolescents' isokinetic trunk strength testing.

Test–retest reliability of isokinetic PT measurements for trunk flexors and extensors data exhibited very low mean differences (610 N·m), and excellent ICC and SEM values. Although trunk extensor concentric torque showed slightly lower ICC and higher SEM values than eccentric, reliability was comparable between 60°/s and 120°/s angular velocities.[13] Test–retest reliability results were also excellent for trunk flexor muscles, with ICC above 0.90 and SEM values below 8% for all the experimental conditions, which are similar to or better than previous reliability analyses conducted with other studies.[27,21]

Concerning endurance variables, studies found moderate-to-high ICC values for the drop in the performance within sets ($0.57 < ICC < 0.82$), in healthy young male and female volunteers.[28,26] Recently, Roth et al.[29] found very good ICC's ranging from 0.85 to 0.96 in adults for isokinetic trunk extension and flexion.

Ben Moussa Zouita et al.[30] found that mean of the trunk extension and flexion torques is 208 Nm (range: 121–360 Nm) and 176 Nm (range, 111–296 Nm), respectively with a ratio of trunk flexion to extension of 0.84 (range, 0.54–1.16). Also, the average trunk flexion to extension ratios varied between 52.6% to 69.7% and 43.9% to 58.6% respectively, in the non-athlete and athlete groups.

DISCUSSION

The purpose of the current review is to present and summarize data about isokinetic trunk strength assessment relative to young, adolescent and adult athletes. Testing position variations, reliability values by age groups, utilization of strength measures and normative data by age groups have been discussed. The information presented within this review are of practical importance for assessment of isokinetic trunk strength and conditioning for professionals in appraising their athlete's current strength level and providing accurate conditioning training programs that correlate with physical performance. Also this data, may serve as reference for prevention of low back pain.

VALIDITY OF ISOKINETIC TRUNK MEASURES

Isokinetic dynamometry can measure trunk flexion and extension strength at various angular velocities and contraction modes (isometric, concentric, and eccentric), and has been found to be safe, reliable, valid and sensitive enough to detect muscle weakness.[13,31] Findley et al.[32] postulated that isokinetic trunk extension and flexion have traditionally been measured in either the sitting or standing position. However, these positions may produce dissimilar levels of PT, work, and power of isokinetic concentric trunk extension and flexion at 60°/s and 120°/s in the sitting and standing positions. They suggested that trunk musculature, including some synergist muscles can partly contribute to external torque differences seen during trunk flexion or extension between sitting and standing positions.[13] Between positions there is likely different recruitment of hip muscles and variation in range of motion.

Although the angle of the hip joint was much different, the anatomical ROM measured in the sitting position was from 100° of extension to 30° of flexion whereas in the standing position ROM was from 190° of extension to 120° of flexion. Changes between sitting and standing isokinetic exercise in the sagittal plane alters the muscle activation-performance relationship, thereby shifting the zone of optimal performance, described as the inverted-U torque production curve.[33] In essence, data are being produced in two completely different ROM's in the different positions.

Szpala et al.[34] compared trunk extensor´s torques and spinal muscles activity during sitting and lying body positions. They found significantly higher electromyographic (EMG) activity in erector spinae muscles during lying, whereas PT values were higher during the sitting position. Therefore, caution should be exercised when interpreting position-specific isokinetic test results that measure trunk flexion.

Reliability of isokinetic trunk measures (Table 1)

Due to the importance of trunk strength, clinicians and coaches must know whether changes in strength over time reflect a real gain or loss, or are the result of the measurement error.[35] Therefore, the validity and reliability of data are important when assessing strength. The validity of data concern how an individual's test performance reflects true performance

Table 1. *Previously reported reliability statistics of isokinetic trunk measures.*

Study	Subjects							Peak torque (N.m)		Ratio%
Study	Characteristics			n	Weight (kg)	Contraction mode	Test velocity °/s	Ext	Flex	F/E
Youth										
Merati et al. (2004)	Adolescents	F	H	40		Con	60 90 120	101 79 59	94 80 68	0.93 1.01 1.15
		M	H	44			60 90 120	135 118 107	109 105 96	0.81 0.89 0.90
Mueller et al. (2011)	Adolescent athletes	F	H	22	63	Con	60	161	111	0.69
		M		48	67			219	146	0.67
Müller et al. (2014)	Adolescents athletes 15.9 year Judo=10, Soccer=1, Swimming=1 gymnastics=1	F M	H	13	69	Con Flex/Ext Rot Ecc Flex/Ext Rot	30 60 120 30 30 30	211 214 187 R: 81 282 81	147 138 129 L: 87 146 88	0.70 0.66 0.71 0.94 0.53 0.94
Müller et al. (2014)	Young athletes 11 -15 years	All M/ F		377	51. 6	Flex/Ext	60°/s	140	97	0.71
		M		233				149	102	0.69
		F		144				125	89	0.73
Adults										
Yahia et al. (2011)	Normal adults	M/F	H LBP	30 30	68 71	Con	60 90	145 76 132 67	123 102 112 90	0.85 1.34 0.85 1.34
Baur et al. (2010)	Normal active adults Race car driver	M	H	13 13	73 71	Con	60 120 60 120	260 237 283 248	212 207 181 191	0.82 0.87 0.64 0.77
Müller et al. (2011)	Normal adults	M/F	H	26	66	Con	60 120	207 190	173 169	0.84 0.89
Ben Moussa Zouita et al. (2018)	High-level Athletes (mean 23.3 years) Boxing Wrestling Weightlifters Nonathlete control (mean 22.3 years)	M	H	18 n=8 n=5 n=5	74.1 74.7	Con	60 90 120 60 90 120	440.05 433.66 345.26 373.01 365.46 344.10	297.34 261.53 211.98 249.23 261.0 190.10	58.6 50.1 43.9 66.2 69.7 52.6
Dervisevic et al. (2001)	Normal adults	M	H	27	78	Con Ecc	30 60 30 60	211 201 249 256	128 116 249 256	0.61 0.58 0.57 0.52

F= female, M= male, H= healthy, LBP= Low Back pain, Con= concentric contraction, Ecc= eccentric contraction, Flex= flexion, Ext=extension, Rot: Rotation, L= left side, R= right side, F/E= Flexion/extension ratio;

and the reliability measures in tests and retests concern the repeatability of the data observed in a sample.[36]

Previous studies regarding the reproducibility of isokinetic trunk strength have focused mainly on the relative parameters, predominantly correlation coefficients.[36] Relative reliability indicates how similar the rank orders of the participants in the test are to the retest.[37] The main problem with relative reliability is that it depends on the variability of the sample. However, absolute reliability is related to the consistency of individual scores;[38] the smaller the variation, the higher the reliability.[39] In addition, they are not variance dependent. Among those indices, the most commonly used are the standard error of measurement, the coefficient of variation of standard deviation and Bland Altman plots.[40] CV and SEM reflect the magnitude of the differences between two measures.[41] Since they are expressed in units that are readily interpretable, extrapolation to new individuals as well as comparison between different measurement tools is possible.[39] Blande Altman plots showed no systematic biases when most of the points are very close to the line of equality. Ultimately, there was good agreement between results from different equipment, without any identifiable trend.

From a practical standpoint, muscle assessment methods using an isokinetic dynamometer are considered reliable and reproducible, with correlation coefficients between 0.93 and 0.99 for peak force values and between 0.91 and 0.96 for total workload values.[42] Isokinetic trunk flexion/extension strength reliability with adults has been reported to be clinically acceptable to excellent with testing velocities of 60°/s and 120°/ (ICC 0.74 – 0.91)[13] and 30°/s and 60°/s (ICC: 0.78-0.91).[43] Müller and colleagues[11] suggested that isokinetic trunk flexion and extension angular velocities higher than 120°/s could increase the error between sessions and large ranges of motion could result in a misalignment between the biological axis of the trunk and the mechanical axis of the dynamometer.

The high reliability of the isokinetic testing of the trunk (high ICCs) is presumably related to several factors, including the standardization of the instructions, the adoption of familiarization procedures, the adjustment of the fixed seat platform according to the size of the members of each individual, the fixed order of the tests, and the supervision of experienced evaluators. Overall, the results of all these studies indicate the robustness of isokinetic measures in assessment of trunk muscle strength.

Despite the efforts made in the field of isokinetic trunk assessment, there is no evaluation protocol to determine the appropriate velocity and through what range of movement the evaluation should be performed,[44] even though there have been attempts.[45] Still, there are indications that low-velocity movements are more reliable for measuring trunk strength.[13,29] Different authors have analyzed the test reliability using peak force,[29,46,47] but it has not been shown which strength manifestation (peak force or mean force) is more reliable for assessing trunk strength. However, the reliability of strength test results is crucial to assess the level of adequate performance and develop a successful rehabilitation or training program[36] for all age groups.

Youth

Trunk isokinetic torque of youth has been measured in a few studies.[48,49] The use of isokinetics for studying muscle torque in children and adolescents is fully accepted and reliable .[50,51] Studies on the extension/flexion torque ratio in limbs and trunk as well as upper and lower body (knee vs. elbow) extension and flexion torque ratios with increasing age in both sexes seem to be sparse.[52]

Godhe et al.[49] suggest that from the youngest ages to adolescence, peak absolute (N.m) and normalized (N.m/kg body mass) torque increases in all measures with highest increase in the trunk activities. For trunk activity, the sex differences start at age 14 years. However, trunk extension/flexion ratios are mainly unchanged with increasing age with no differences between sexes. Normalizing data (N.m/body mass) reduces the rate of increase in all measurements in both sexes but does not change the rank order.

Choice of isokinetic testing protocols with pediatric populations may be influenced by participants, test equipment availability, cost and specificity of testing. There are numerous generic protocol considerations specific to paediatric groups such as adaptation of equipment, stabilization and technique, habituation and learning effects, and safety. Some dynamometers can be ordered with paediatric specifications such as adjustable seat length to accommodate the short femurs of children and short attachments.[53]

In a recent review on pediatric strength testing, De Ste Croix[24] stated that test-retest-variability in isokinetic strength testing in children ranges between 5 and 10%. Furthermore, De Ste croix [24] deduced in his review that extension movements were more reliable than flexion movements, concentric muscle action was more reliable than eccentric work and that reliability was reduced with increased testing velocity, regardless of joint tested. With adolescents, Carvalho et al.[25] reported questionable as well as clinically acceptable to excellent reproducibility in adolescent basketball players for isokinetic strength testing (ICC: 0.72-0.99). Lindsay et al.[26] reported an acceptable reproducibility in the adolescent cohort with isokinetic trunk rotation and endurance at a testing velocity of 30°/s (ICC: 0.86-0.87). Müller et al.[5] found excellent reliability (0.91-0.94) with adolescents' isokinetic trunk strength testing.

Sex differences

Isokinetic strength variables in flexion and extension efforts showed high ICC values in both males and females ($0.74 < ICC < 0.91$).[54] These results differ from those by Dvir and Keating[45] and Keller et al.[55] who found higher isokinetic trunk extension reliability values for females and males, respectively. Dvir & Keating[45] found partially clinical acceptable reproducibility of an isokinetic test protocol (concentric/eccentric; 10°/sec, 40°/ sec) measuring trunk extension strength in healthy men and women with women (ICC: 0.70-0.87) showing higher ICCs than men (ICC: 0.52-0.78). The test-retest correlation coefficients were generally lower in males (0.52–0.78) than in females (0.70–0.87) probably as a result of a higher difficulty in controlling the males body position during the protocol. Hence, the greater anthropometric dimensions and the higher experience in maximum efforts of some males may have allowed them to exert higher forces.[55] So inappropriate strapping could have changed the initial position, affecting the pelvic axis alignment.[43]

Normative data (Table 2)

Children and adolescents

With children and adolescent athletes, isokinetic testing is often applied to describe and evaluate individual and population specific characteristics like age- or sex-related changes in strength over growth and maturation.[24] However, there are difficulties in assessing maximum strength in adolescents due to their inexperience with producing maximal strength.[24, 56,57]

Balague´ et al.[48] observed that peak low back torque extension is at its maximum level in 12-year-old girls and in boys, from the age of 14 years it increases constantly. Among the 14 to16-year-olds, on the other hand, whether they are healthy or not, the boys appear stronger than the girls, with higher values for the trunk extensors and flexors. In a study involving 62 school children with an average age of 12 years. Mérati et al.[58] found that isokinetic performances pertaining to peak torque, total workload and mean power for trunk extensors at 60°/s and at 90°/s were higher for boys.

Bernard et al.[59] suggests that in populations of children and adolescent (11-16 years), they could not deduce reference values for the trunk isokinetic parameters; all they could do in this respect was establish frameworks for values that would be adjusted as the series of tests increase in number. For girls, the maximum moment of force (MMF) and mean power (MP) values for the trunk flexors and extensors ranged from 1.7 to 2 and 2 to 2.8 times body weight respectively. For 11 to 13 year old boys, MMF and MP values for the trunk flexors and extensors ranged from 1.4 to 2 and 1.7 to 2.7 times body weight respectively, and for 14 to 16-year old boys 2.4 to 2.8 and 2.4 to 3.5 times the body weight, respectively. In boys, trunk flexors and extensors ratios normalized to body weight, decreased with growth from 0.72–0.91 to 0.67–0.77. While, the girls show more elevated trunk flexors and extensors ratios, ranging from 0.81-0.94 to 0.75-0.95 for the controls. Bernard et al.[59] observed that values for trunk concentric peak moment were higher than those found by Delitto et al.[60] An accurate comparison of these values between studies is hampered by the lack of data on range of motion and age groups of the individuals.

Table 2. *Normative data.*

Study	Subjects	Evaluation	Joint	Movment	Type of contraction	Velocity (°/sec)	Values
Delitto et al. (1991)				Extension Flexion		60, 120, 180	0.74–0.88 0.74–0.88
Dvir and Keating (2005)	Healthy Men and Women		Trunk	Extension	Concentric Eccentric	10 40	acceptable reproducibility ICCs: 0.52-0.78 ICCs: 0.70-0.87
De Ste Croix (2012)	Children	Test-retest-variability		Extension Flexion	Concentric Eccentric	Reduced with increased testing velocity, regardless of joint tested.	5 and 10%. Extension movements were more reliable than flexion movements Concentric muscle action was more reliable than eccentric work
Carvalho et al. (2011)	14 to 16-year-old basketball players	Reliability	Trunk		Concentric Eccentric		ICC from 0.72 to 0.99
Lindsay et al. (2006)	Adolescent		Trunk rotation			30	(ICC: 0.86-0.87).
Müller et al (2014)	Healthy adolescents (N=13)	Twice	Trunk	Rotation Flexion / Extension	Concentric Extension Concentric and Eccentric	30 120 30	Between 0.65 – 0.90. (0.94) (0.91)
Dervisevic et al. (2007)	27 young healthy male (21.3± 3.7 yrs)	Twice over a period of one week	Trunk	Flexion / Extension	Concentric/ Eccentric	30 60	acceptable to excellent reproducibility (ICC between 0.78-0.91)
Roth et al. (2017)	15 healthy sport students (8 female and 7 male) aged 21 to 26		Trunk	Extension and Flexion		60 150	Excellent Relative reliability (ICC: 0.85-0.96) very good ICC's ranging from 0.85 to 0.96
García-Vaquero et al. (2016)	57 healthy and physically active young men (*n* = 28) and women (*n* = 29)	4 trials of 15 maximum	Trunk	Absolute and relative peak torque and total work with Flexion–Extension Endurance ratio	Concentric	120	ICC= >0.74 Moderate to high ICC values (0.57 < ICC < 0.82).
Keller et al. (2001)			Trunk	Flexion Extension		60	NA 0.80-0.98

F= female, M= male, H= healthy, LBP= Low Back pain, Con= concentric contraction, Ecc= eccentric contraction, Flex= flexion, Ext=extension, ROT: Rotation, L= left side, R= right side, F/E= Flexion/extension ratio

It has been shown that growth and the resulting anthropometric parameters are directly related to motor performance in young people and that the latter stabilizes at the end of growth.[61] Philippaerts et al.[62] followed prospectively for five years, the growth in size and weight of 33 young footballers, initially aged 12.2 (± 0.7) years and found a correlation between peak growth and trunk muscle strength, the endurance of the upper body muscles, balance and speed of running among other measures of physical performance.

However, Godhe et al.[49] presents a complete set of different ratios trunk activities in both sexes and all age groups from 8 to 15 years. For the trunk, a sex difference is only seen at 15 years for extension and at 14 and 15 years of age for flexion. For trunk extension and flexion higher PT normalized values are found in boys compared to girls only at three points with regard to age groups; at the 12th and 15th year age groups for flexion and in the 12th year age group for extension. The increase in average absolute (N.m) values from the 8th to the 15th year age group is highest in the trunk.

Isokinetic assessment in pediatric populations has been utilised to describe the age and sex associated changes in strength,[63,51,24] to explore the growth and maturational effects on strength,[51,64] to examine the effectiveness of training studies.[65,66] Pediatric researchers are starting to move from beyond using isokinetic assessments in isolation, and for simply descriptive study, but are now trying to integrate isokinetic data with other forms of data to explore the complex changing mechanisms that are involved in the development of dynamic strength with age.

Adults

In healthy adult subjects, trunk strength is typically greatest with sagittal plane extension followed by sagittal plane flexion. It is clear that athletes tend to show the highest trunk strength values, but also the smallest ratio of trunk flexion to extension.[67] Elite athletes show a capacity of between 150–240 Nm for trunk flexion and between 200–450 Nm for trunk extension.[68] In this respect, adult athletes (rowers, wrestlers) have higher PT values compared to non-athletes and relatively higher trunk extension strength torques (reduced flexor/extensor ratio).[69] Ratios of trunk flexion to extension in healthy untrained adults usually range between 0.7–0.9 but in athletes, the ratio tends to be between 0.5–0.7, which occurs in tandem with increased trunk extensor strength.[5] However, few previous investigations have directly compared trunk flexion and extension strength and ratios between athletes and non-athletes, and explored the impact of angular velocity on trunk flexion and extension strength and ratios.

To summarize, previous studies indicate differences in isokinetic PT for trunk sagittal and transverse efforts as a function of age, subject populations (e.g. trained vs. untrained) and sex.[59] Moreover, athletic subjects show more muscle capacity than sedentary subjects.[70] A normal flexor/extensor ratio is lower than 1, ranging from 0.80 to 0.85 according to Gremion et al.[70] without correction for gravity.

Recently Ben Moussa Zouita et al.[30] compared maximal concentric isokinetic trunk extension and flexion torques, power and trunk extension and flexion torque ratios between high-level athletes and a control population. In general, there were trends for increasing trunk extension and flexion torques and power with increasing angular velocity in both groups, although the effect was more marked for trunk extension in the athlete group than in the non-athlete group. Additionally, it was found that the trunk extension torque of athletes was significantly higher than the non-athlete group at 60˚/sec and 90˚/sec but not at 120˚/sec, and also that the trunk extension power of athletes was significantly higher than the control group at 90˚/sec and 120˚/sec but not at 60˚/sec. In contrast, there was no difference between the athlete and control groups for trunk flexion power at any angular velocity.

Both athletes and non-athletes displayed greater torque and power in trunk extension, at all angular velocities versus trunk flexion. This is in accordance with previous reports that the trunk extensors are stronger than the trunk flexors.[59] Athletes displayed greater trunk extension torque and power than non-athletes, but that there was no difference between athletes and non-athletes in relation to trunk flexion torque and power. In accordance with previous literature, athletic subjects display greater lumbar muscle capacity than sedentary subjects.[69] Few studies have previously assessed the torque-angular velocity and power-angular velocity relationships for the trunk flexor and extensor muscles. Van Damme et al.[71] found that the angular velocity of isokinetic trunk extension exercises influences the recruitment of the back muscles.

The ratio of the PT of the flexors to the extensors can serve as a parameter to assess the muscular balance of a joint. Simbala et al.[72] assessed a group of asymptomatic sedentary individuals, and reported a ratio of the PT of the flexors to the extensors of 81% for males.

Relation of isokinetic trunk strength, sport and performance (Table 3)

The contribution of the trunk musculature to many sports (e.g. taekwondo, judo, tennis, golf, baseball, handball, rowing, etc.)[28] and daily life activities, has aroused considerable interest in trainers, clinicians, and researchers.[73] In the field of sports, it is thought that increases in the ability to exert the maximum trunk muscle force (trunk muscle strength), as well as the ability to exert trunk muscle force repeatedly or continuously over a long period of time (trunk muscle endurance), can improve athletic performance [28] and help prevent and treat back disorders in individuals with trunk muscle weakness.[74]

Table 3. *Relation of isokinetic trunk strength, sport and performance.*

Study	Subject Characteristics					Contraction mode (con/ecc)	Test velocity °/s	Peak torque N.m Ext	Flex	Physical performane	Correlation
Hall et al. (1992)	23.1 years 22.2 years	M F	H	23 28	73.1 61.7	Con Ecc Con Ecc	15° /s	146 169 95 111		Sit-up tests: Repetitions correctly performed in 1 min) - *Kraus-Weber Test* 39 - *Robertson Curl-up* 76 - *AAHPERD 49* - *Kraus-Weber Test.* 33 - *Robertson Curl-up Test* 63 - *AAHPERD* *42*	Con/*Robertson Curl-up r=-0 .41* Ecc *Robertson Curl-up r=-0.38* Con/*Kraus-Weber Test.* r =0.42 Ecc /*Kraus-Weber Test r=0.40* Ecc /*AAHPERD r=0.32*
Roeter et al. (1996)	Elite level tennis players Junior 13 and 17 years			60		Con	60 120			Measurements of strength, power, speed and agility, endurance and flexibility: The correlated measurements included the total distance thrown on a forehand, backhand, overhead, and reverse overhead medicine ball toss	range 0.47–0.82, which were used in the field a a measurement of power (P 0.01)
Kale and Kırkaya (2013)	Voluntary Athletes from different sports 20.9 year			19	64.7	Con	30 90 120			Sprints (10m, 20m, 30m, and 40m) a non-motorized treadmill. V10m, V20m, V30m, and V40m) Horizontal ground reaction forces (HGRF-10m, HGRF-20m, HGRF-30m, and HGRF-40m)	Statistically highest significan correlations have been found between V40m and isokinetic trunk flexion-extension peak torques (30°.s-1, 90°.s-1, and 120°.s-1) r= 0.846 There were significant relationships of horizontal ground reaction forces with isokinetic trunk extension-flexion peak torques at 30°.s-1 90°.s-1, and 120°.s-1 0.542<r< 0.798
Xiong et al. (2014)	Elite Weightlifters'	M	H	12		Con	The relative peak torque of the trunk			Snatch and clean and jerk performance subjects'snatch/weight,Clean and Jerk weight/weight	Snatch/weight demonstrates moderate positive correlation significantly with back extensor The clean and jerk/weight and the relative peak torque value of jerk trunk extensor have significantly moderate positiv correlation with the relative peak torque values of the kne extensor
Kunitson et al. (2015).	International level monfin swimmers 16.9- 17.6 year	M F	H	9 8	76.0 68.6	Con	Trunk extensors and flexors at 60°/sec			Performed 100 meters monofin surface swim	There was a strong correlation (p<0.05) between swimming time and trunk flexors (r =-0.77 at angle 20°) in male swimmers
Barbado et al. (2016)	International Judokas National judokas	M	H	11 14	74.4 75.2	Con	120	461 400	231 229	Sudden loading, to assess trunk responses to unexpected external perturbations; stable and unstable sitting, to assess the participants' ability to control trunk balance.	Few and low (r < 0.512 significant correlations wer found between strength endurance and stabilit parameters
Thevenon and Blanchard (2003)	Healthy subjects 28.2year	M W	H	25 25	60.7	Con	120 90 60 30			Finger to floor – Lumbar Schober index: – Dorsal Schober index: Assessment of hamstring extensibility – Assessment of hip flexors extensibility	-a negative relation between finger to floor distance and maximal torque and work of trunk flexors at 30, 60 and 90◦/s.r= −0.54 – a negative relation between lumbar Schober index and trunk extensors maximal torque and work at all speeds, r=−0.42 -a positive relation between lumbar Schober index and flexors/extensors ratio at all speed. r= 0.61 – a positive relation between hamstring extensibility and work of trunk flexors at 30, 60 and 90 ◦/s. r= 0.53

F= female, M= male, H= healthy, LBP= Low Back pain, Con= concentric contraction, Ecc= eccentric contraction, Flex= flexion, Ext=extension, L= left side, R= right side, F/E= Flexion/extension ratio, AAHPERD= The American Alliance for Health, Physical Education, Recreation and Dance

For these reasons, many field and laboratory protocols have been developed to assess trunk muscle strength and endurance in sport, fitness, clinical and research settings.

Based on findings from 15 correlation studies, Prieske et al.[75] observed only small-sized relationships between measures of trunk muscle strength and physical performance. In addition, the results of 16 intervention studies indicated only small-to-medium-sized effects of core strength training compared with no training or regular training on proxies of physical performance. Of note, Prieske et al.[75] discussed a major limitation of their findings and questioned the external validity of the applied trunk muscle strength tests. Most included studies measured trunk muscle strength by means of a trunk muscle endurance test using an isometric plank test. Prieske et al.[75] postulated that these tests do not appropriately evaluate maximal force production capacities in dynamic sport-specific activities.

Zinke et al.[76] suggest that isokinetic trunk rotator training (8 weeks) in conjunction with canoe-specific training resulted in increased isokinetic trunk rotator torque (concentric) at slow and fast movement velocities. In addition, a strong relationship was found between peak isokinetic torque and peak paddle force (canoe-specific performance parameter).

Isokinetic Assessment Relationship to Low Back Pain (LBP) Risk

Typically, isokinetic trunk assessments examine joint range of motion, muscular strength, power and balance between agonists and antagonist muscles, as all of these variables are considered crucial for optimal performance whilst playing a role in reducing an athlete's risk of injury. Muscle strength ratios are commonly tested to describe unilateral antagonist to agonist strength properties, functionality and imbalances.[77,78,80] An increased antagonist/agonist imbalance may demonstrate failure of the antagonist muscles to produce enough strength to decelerate agonist maximal torque actions during a required movement, increasing the likelihood of muscle and ligament injuries during sports performance and functional activities.[78,79,80] Therefore, unilateral imbalances have also been investigated as possible causes leading to a low back pain (LBP) condition.[81] Some authors have detected an association between the episodes of BP and decreased truck muscle strength.[82,83] Some authors attributed this to the endurance of the trunk extensor muscles.[84,85] However, other researchers failed to find any correlations between trunk muscles strength and back pain.[48] Thus, the relation between trunk muscles strength and back pain occurrence need to be investigated. Trunk muscles strength cannot be accurately examined with conventional methods.[42] The isokinetic dynamometer provides objective assessment of muscle function and can be used to study the relationship between the back pain and trunk muscles.[86] Flexor/extensor imbalances have been tested as a possible cause of BP.[81,87] The normal flexor/extensor ratio ensures that the flexor muscles produce sufficient contraction to decelerate the extensor muscles during trunk movements preventing ligament and muscle injuries during explosive or daily activities.[88,89,90]

Gabr and Eweda[91] obtained greater trunk flexor/extensor ratios at 120˚/s among patients group, this means that trunk extension movements may result in more prominent trunk flexion strength than extension, resulting in a trunk strength imbalance.[87] Likewise, Lee and his colleagues,[82] revealed a significant difference in the trunk flexor/extensor ratio between the healthy subjects and the BP sufferers. In contrast, Ripamonti and colleagues[92] suggested that the flexor/extensor ratio cannot be considered as a predictive factor in patients with back pain.

CONCLUSION

Due to the importance of trunk strength, clinicians and coaches must know whether changes in strength over time reflect a real gain or loss, or are the result of the measurement error. Muscle assessment methods using an isokinetic dynamometer are considered reliable and reproductible, with high correlations to peak strength values and flexor/extensor ratios in children, adolescent, and adults. Therefore, the validity and reliability of data are important when assessing strength. However, caution should be exercised when interpreting position-specific isokinetic test results that measure trunk flexion (standing vs seated position). Still, there are indications that low-velocity movements are more reliable for measuring trunk strength.

In adolescence, boys appear stronger than girls, with higher values for trunk extensors. Trunk flexors and extensors ratios decrease with growth. Data of isokinetic muscle performance of the trunk seems to be correlated not only to anthropometric parameters but also to sports discipline and training volume. It seems that the effects of sport on the muscular strength of the trunk have both a preventive factor and a possible risk factor for low back pain. There is evidence for an association between high physical workloads and back injury.

For adults, trunk strength is usually greatest with sagittal plane extension versus flexion. Athletes displayed greater trunk torque and power than non-athletes. In terms of relationship to sports practice, the current literature has shown the principle of training specificity indicates that exercise choice should match the movement patterns and muscle actions of the sport as closely as possible if one is to achieve optimal levels of transfer. The sport-specific trunk motions involved in each sport can induce different muscular adaptations in the corresponding trunk muscles.

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