RELATIVE AND ABSOLUTE RELIABILITY OF ISOMETRIC AND ISOKINETIC SHOULDER MAXIMAL MOMENT AND FLEXION/EXTENSION RATIOS IN GYMNASTS

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Abstract

Shoulder strength is essential for gymnasts in order to succeed in their sport, but little research has examined isometric and isokinetic shoulder moment and flexion/extension ratios. The purpose of this study was to evaluate the relative and absolute reliability of isometric and isokinetic shoulder moment and shoulder flexion/extension ratios. Fifteen international level male gymnasts (age: 19.3 ± 2.3 years) participated in the study. Two identical measurements with one week interval were applied using the isokinetic Humac Norm 770 dynamometer at three angles (45º, 90º, and 135º) for isometric and at three angular velocities (60º/s, 180º/s, and 300º/s) for concentric and eccentric action modes. All measurements were conducted in a range of motion of 10º to 180º, in supine position, bilaterally, with the elbows fully extended. Notwithstanding a small systematic bias (due to testing/learning) from measurement 1 to measurement 2 significant in four parameters, the results supported the reliability of the measurements. Relative (a) and absolute (b) reliability values were ranged as follows: (a) intraclass correlation coefficient (ICC) 0.73 to 0.96 and (b) standard error of measurement (SEM)(%) (calculated using ICC) 3.4 to 11.2%, minimum detectable change (MDC)(%) 10.7 to 31.1%, SEM_e(%) (calculated using mean square error) 0.1 to 23.4%, MDC_e(%) 1.6 to 48.8%, and coefficient of variation (CV)(%) 8.6 to 17.8%. Bland-Altman analysis showed that the bias was lower than 10% and limits of agreement (LOAs) were lower than 35%. SEM_e(%) and MDC_e(%) were considered as more important and meaningful to detect any significant change between two measurements, or to detect muscle imbalances. Considering the limitations of the study, results from the present study provided assessment methods and normative data that could be very helpful for researchers and practitioners to evaluate the effectiveness of intervention programs aiming at the development of shoulder muscle strength.

Keywords: *Reliability, shoulder, isokinetics, flexion/extension ratio, gymnastics.*

INTRODUCTION

The shoulder joint plays a vital role in artistic gymnastics. Shoulder strength and flexibility are essential for gymnasts in order to achieve a safe performance with a high degree of aesthetic and technical mastery. Gymnasts use their arms extensively during their sport activity (Caine, 2003). During the execution of gymnastic skills, gymnasts use their arms in low angular velocities (e.g., flexion-extension of the shoulder during the swings in frontal position on the parallel bars) and high angular velocities (e.g., rapid shoulder flexion during the rise to the handstand during the upswing in a clear hip circle, rapid shoulder flexion during the first jumping back phase of the back handspring). The safe and effective execution of weight bearing skills requires supplementary strength of the arm muscles and stability of all contributing joints (Caine, 2003). Contrary to overhead throwing athletes who use their arms in an open kinetic chain, gymnasts use their upper extremities very often in closed kinetic chain skills with the hand supported on a floor, balance beam, or pommel horse (Cools, Geerooms, Van den Berghe, Cambier, &Witvrouw, 2007).

Isokinetic dynamometers make it possible to evaluate with good reliability muscle strength in the concentric or eccentric mode across a wide range of angular velocities (Ellenbecker & Davies, 2000; Mikesky, Edwards, Wigglesworth, & Kunkel, 1995; Walmsley & Pentland, 1993). Furthermore, isokinetic dynamometers can be used to assess the agonist-antagonist strength balance (conventional and dynamic control ratio), a significant index in terms of shoulder function and predisposition to shoulder pathology (Bak & Magnusson, 1997). However, some researchers have provided concerns about the reliability of isokinetic assessment of the shoulder, due to its complex kinematics and its relatively extensive mobility (Mayer, Horstmann, Kranenberg, Röcker, & Dickhuth, 1994; Plotnikoff & MacIntyre, 2002).

Over the past few decades, isokinetic muscle strength at the shoulder joint has been widely studied in muscle imbalance studies in swimming (e.g., Bak & Magnusson, 1997) baseball (e.g., Mikesky et al., 1995), water polo (e.g., McMaster, Long, & Caiozzo, 1992), and other overhead sports (e.g., Yildiz et al., 2006). Compared with other athletes, gymnasts use a unique kinetic chain during the execution of specific gymnastic skills, including specific muscle activation of the upper extremities. Adaptations in the shoulder muscles may influence the quality of the performance and the risk of injuries due to overuse (Cools et al., 2007). Because of the relevance of the kinetic chain during the execution of gymnastic skills using flexion-extension of the shoulder, isokinetic dynamometers provide the ability to reproduce and evaluate these functions of the shoulder. However, only few studies have assessed the performance of the shoulder muscles in gymnasts (Cools et al., 2007; Siatras, Douka, & Milosis, 2010; Zhou, Liu, Cheng, & Jiang, 2014) and no research has been reported in literature regarding the evaluation of isometric and isokinetic (concentric and eccentric) shoulder strength of flexors and extensors and flexion-extension ratios in gymnastics with bilateral arm activation.

The aim of the present study was to determine the relative and absolute reliability of the flexion and extension isometric (FLisom, EXisom), flexion and extension concentric (FLcon, EXcon) and eccentric (FLecc, EXecc) peak moment (PM) of gymnasts, when performing shoulder maximum flexion-extension with both upper arms in supine position. An additional aim was to analyze the relative and absolute reliability of moment ratios such as flexion concentric/extension concentric (FLcon/EXcon) and flexion eccentric/extension concentric (FLecc/EXcon) ratios (conventional) and extension eccentric/flexion concentric (EXecc/FLcon) ratios (dynamic control). It has been suggested, that for a more complete picture of the strength balances for dynamic and static muscle actions, an evaluation of a combination of these dynamic control ratios is needed (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998). It was hypothesized that (a) all the measurements would show acceptable relative and absolute reliability and (b) that based on the literature the conventional ratios obtained from the present study would provide important clues for the balanced development of highly competitive gymnasts' shoulder strength.

METHODS

Participants

The sample size was calculated using MedCalc software to achieve a power of 0.90 for an intraclass correlation coefficient (ICC) under the following assumptions: alpha = 0.05; ICC > 0.80, considered an ICC over 0.90 as high, between 0.80 and 0.90 as moderate and below 0.80 as low (Atkinson & Nevill, 1998; Hopkins, 2000). A minimum of 12 subjects was required for the measurements. However, in order to account for potential study dropouts, some additional subjects were allocated to participate in the measurements. Thus, fifteen male gymnasts (age: 19.3 ± 2.3 years, height: 169.6 ± 6.3 cm, mass: 67.2 ± 6.5 kg) with no previous experience in isokinetic measurements volunteered to participate in the study. All of them were mature/senior gymnasts who take part in international competitions, with more than 10 years of intensive training, and with a minimum of 18 hours of training per week. The majority of the athletes were competed in all gymnastics apparatus and four of them specialized in still rings. All gymnasts were right-hand dominant (the hand preferred for writing), without prior orthopedic problems as regards the shoulder joint. According to the Ethical Committee of the Aristotle University, all the subjects and their coaches were informed about the objectives of the study and the possible difficulties or risks in the implementation of the protocols. Before participating, all subjects gave their written informed consent. Signed parental consent was obtained for the two gymnasts who were under the age of 18 years. Approval of the study was obtained from the Laboratory of Exercise Physiology-Ergometry. The measurements were performed in a pre-competition period.

Measures

Shoulder muscle strength was evaluated using an isokinetic dynamometer (Humac Norm 770) calibrated according to the manufacturer's instructions (Humac Norm manual; Computer Sports Medicine, Inc.; CSMI, 2006). A second handgrip rotation was inserted on the elbow/shoulder adapter assembly (Figure 1). The starting position (10º) was set by the subjects fully extended arms near their hips and the full flexion (180º) was set by the subjects fully extended arms in the extension of the body. The compromised axis of rotation of the moment arm passed through the shoulder joint center when the shoulder was at 90 degrees flexion, to ensure the minimum displacement of the center of rotation in the range of motion for each measurement. The alignment between the dynamometer rotational axis and the shoulder joint rotation axis was checked for each subject at the beginning of each trial.

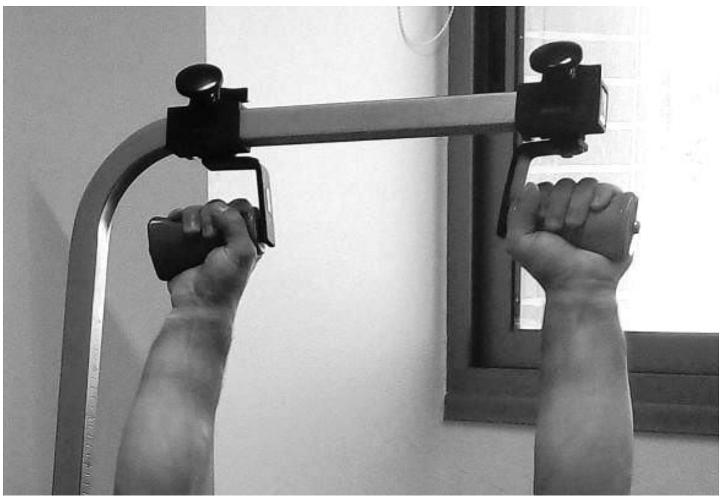

Figure 1. Customized elbow/shoulder adapter assembly.

Two identical measurements with a one-week interval were performed to determine intersession variability (test-retest). All measurements were recorded by the same investigator in order to eliminate inter-tester variability. All measurements were done according to a standardized protocol: measurements were done in a supine position; subjects were strapped down with two Velcro straps across the chest, one across the pelvis and one across the thigh. Subjects performed all measurements holding and pressing the elbow/shoulder adapter assembly with the arms fully extended in the elbow joint in overhand (dorsal) grip (usually performed in a variety of gymnastics skills) (Figure 1). Gravity correction was performed according to the recommendations of the CSMI (Humac Norm manual; Computer Sports Medicine, Inc.; CSMI, 2006).

The same standardized procedure was followed by all the participants. Subjects were asked to refrain from strenuous exercise 24 hours prior to the day of testing. After the anthropometric measurements, the subjects warmed-up for six minutes on an arm-cycle ergometer (MONARK 881; in forward and backward rotation) with progressively increased load, and for three minutes performing shoulder flexion-extension with an elastic band, followed by three minutes of shoulder muscles' stretching. After that, subjects were placed in the dynamometer chair. Before the recording of the measurements, subjects performed 5 submaximal consecutive isokinetic concentric extension-flexion warm-up repetitions at 60º/s and 3 repetitions at 180º/s so as to familiarize with doing so over the full range of motion. Subjects performed for practice one submaximal repetition prior to each test for each contraction mode and angle or angular velocity.

Isometric measurements were performed first at 45º, 90º, and 135º of shoulder flexion. One isometric contraction of shoulder extensor and flexor muscles was performed and recorded for each angle. Subjects were consistently instructed to produce their maximal force rapidly (as fast and forceful as possible) and to maintain the contraction for 6 s so to ensure that the maximum moment value was obtained (Moudgil & Karpovich, 1969). According to literature, isokinetic concentric and eccentric movements consisted of three consecutive reciprocal shoulder contractions (extension-flexion for concentric and flexion-extension for eccentric) performed at three angular velocities; 60º/s (low), 180º/s (moderate), and 300º/s (high) (Ayala, Sainz de Baranda, De Ste Croix, & Santonja, 2013). Taking into consideration the recommendation of Mayer et al. (2001) that at 300º/s a range of at least 60º is required to obtain an isokinetic contraction, this angular velocity was included as suitable and feasible due to the wide range of motion (10º to 180º) of the measurements of the present study. For both concentric and eccentric repetitions, subjects were exhorted to push⁄pull as hard and fast as possible and to complete the full range of motion. Subjects were allowed to recover passively for 30 s between sets and for 60 s between different measurements. On-line visual feedback of the instantaneous moment was provided graphically to the subjects on a computer screen. Furthermore, the subjects were given standardized verbal encouragement by the investigator.

Analysis

Statistical analysis was performed with SPSS, Microsoft Excel and MedCalc software. The level of significance was set at $P < 0.05$. Mean and standard deviation (SD) values PM for each isometric contraction and the average PM of the three repetitions for concentric and eccentric contraction at different angular velocities were calculated. PM is the strength parameter that has received the most attention in the study of its reliability (Ayala et al., 2013). Conventional (FLisom/EXisom, FLcon/EXcon, and FLecc/EXecc) and dynamic control ratios

(FLecc/EXcon and EXecc/FLcon) were calculated for the three angles and the three angular velocities. Normality of the data was tested using the Shapiro-Wilks test. Homogeneity of variance between the two measurements was tested with the Levene's test. A repeated-measures ANOVA was performed to primarily test whether the two sets of scores were significantly different from each other (detection of systematic biases) (Atkinson & Nevill, 1998; Weir, 2005). Heteroscedasticity was examined, by plotting the residual versus predicted values and calculating the Pearson's correlation (Atkinson & Nevill, 1998).

Following the recommendations of Atkinson and Nevill (1998) for sports clinicians and researchers, a number of statistical methods for assessing reliability were applied and interpreted in the present study. Relative reliability as regards the degree to which individuals maintain their rank order in a sample with repeated measurements was evaluated using the intraclass correlation coefficient (ICC)$_{(2,1)}$ (Atkinson & Nevill, 1998; Hopkins, 2000; Weir, 2005). Absolute reliability is the degree to which repeated measurements vary for a given population (Hopkins, 2000; Weir, 2005). One indicator of absolute reliability is the 'standard error of measurement' (SEM) (Thomas & Nelson, 1990).

The SEM was calculated by the equation: $SEM = SD \times \sqrt{1 - ICC}$ (Baumgarter, 1989; Thomas & Nelson, 1990). However, this way of calculation has been criticized as not a true indicator of absolute reliability because it is sensitive to population heterogeneity (Atkinson & Nevill, 1998) and is affected by the form of ICC (Weir, 2005).

Thus, the SEM was also estimated as the square root of the mean square error (MSE) term in a repeated measurement ANOVA: $SEM_e = \sqrt{MSE}$ (Bland & Altman, 1996; Hopkins, 2000; Weir, 2005). This type of SEM (SEM_e) is largely independent of the population from which it was determined and thus, is not affected by between-subjects variability as is the ICC (Weir, 2005). For the better interpretation of the results the SEM and SEM_e were calculated and presented as a percentage of the mean value of the PM: $SEM(\%) = \frac{SEM}{mean\ of\ 2\ sessions} \times 100$ and $SEM_e(\%) = \frac{SEM_e}{mean\ of\ 2\ sessions} \times 100$.

In order to achieve a better practical interpretation of the reliability results, the 95% limits of agreement for the determination of the minimum detectable change (MDC) (or smallest real difference), were calculated from the SEM. MDC reflects the smallest amount of change in score which is outside an error and which is due to a real change in score and not due to the error in measurement (Atkinson & Nevill, 1998; Hopkins, 2000; Impellizzeri et al., 2008; Weir, 2005). MDC estimation is based on SEM and expressed in original units of measurement: $MDC = \pm 1.96 \times \sqrt{2} \times SEM$ and $MDC_e = \pm 1.96 \times \sqrt{2} \times SEM_e$. The 1.96 value in the equation is the z score associated with a 95% CI and represents the difference between the measured value and the 'true' one for 95% of observations. The multiplier square root of 2 is included because of the two measurements per subject considered. MDC index approximates to the limits of agreement statistic (95% LOA). For the better interpretation of the results the MDC and MDC_e were calculated and presented as a percentage of the mean value of the PM: $MDC\ (\%) = \frac{MDC}{mean\ of\ 2\ sessions} \times 100$ and $MDC_e\ (\%) = \frac{MDC_e}{mean\ of\ 2\ sessions} \times 100$.

The use of a dimensionless statistic like the coefficient of variation (CV) was also calculated, because as stated by Fetz and Miller (1996) the reliability of different measurement tools can be compared. Furthermore, as a ratio statistic, the CV is useful if heteroscedasticity is present in the data (Atkinson & Nevill, 1998). The CV was calculated by the equation: $CV(\%) = 100 \times (SD \times \sqrt{2}) \times (Average1 + Average2)$ (Portney & Watkins, 2000).

Finally, Bland-Altman plots were conducted to visualize the repeatability of the measurements. The proportion of scores at two standard deviations of the mean difference between test-retest values was taken as a parameter of agreement. According to Bland and Altman recommendations, 95% of the data points should lie within ± 2s of the mean difference (Bland & Altman, 1996).

RESULTS

Tables 1 and 2 present the Mean ± SD, ICC, SEM(%), MDC(%), SEM_e(%), MDC_e(%), and CV(%) of shoulder strength and shoulder strength imbalance (conventional and dynamic control) ratios respectively, obtained for the two measurements. All variables presented normal distribution according to the Shapiro-Wilks test. Homogeneity of variance between the two measurements was confirmed by Levene's test. Analysis of systematic biases by repeated measures ANOVA found no significant differences except for FLcon and EXcon at 180º/s, EXcon at 300º/s, and EXecc at 300º/s. The Pearson's correlation coefficient of the absolute differences between test measurements 1 and 2 and the mean of the two test measurements was not significant except for the FLcon at 300º/s, FLecc/EXcon at 300º/s and FLecc/EXcon at 180º/s. After the logarithmic data transformation, Pearson's correlation coefficient was still significant, thus results from original data were presented.

Isometric shoulder PM ranged from 194.73 to 146.87 Nm (flexion) and from 229.40 to 257.07 Nm (extension) at 45º, 90º, and 135º for the two measurements. Isokinetic concentric PM ranged from 159.53 to 94.80 Nm (flexion) and from 201.13 to 118.33 Nm (extension), while eccentric PM ranged from 180.27 to 204.40 Nm (flexion) and from 194.40 to 276.27 Nm (extension) at 60º/s, 180º/s, and 300º/s for the two measurements. Conventional ratios ranged from 0.84 to 0.59 for isometric shoulder strength, from 0.79 to 0.85 for concentric, and from 0.74 to 0.78 for eccentric isokinetic strength at 60º/s, 180º/s, and 300º/s. Dynamic control ratios ranged from 0.98 to 1.74 for FLecc/EXcon, and from 1.69 to 2.87 for EXecc/FLcon isokinetic strength at 60º/s, 180º/s, and 300º/s.

In the present study, ICC values for shoulder strength indices ranged from 0.73 to 0.96 were considered low in 3 cases, moderate in 4 cases and high in 9 cases. Correspondingly, ICC values for shoulder strength conventional ratios ranged from 0.81 to 0.93, were considered moderate in 6 cases, and high in 3 cases and for dynamic control ratios ranged from 0.74 to 0.89 (except FLecc/EXcon at 60º/s; 0.46), were considered low in one case and moderate in 4 cases (Tables 1, 2).

SEM(%) values (calculated using ICC) for shoulder strength indices ranged from 3.4 to 7.9% and MDC(%) values ranged from 9.4 to 21.8%. SEM(%) values (calculated using ICC) ranged from 3.9 to 7.1% for shoulder strength conventional ratios and from 7.2 to 11.2% for dynamic control ratios. MDC(%) values ranged from 10.7 to 19.8% for shoulder strength conventional ratios and from 20.1 to 31.1% for dynamic control ratios. SEM_e(%) values for shoulder strength indices ranged from 5.3 to 23.4% and MDC_e(%) values ranged from 1.6 to 48.8%. SEM_e(%) values ranged from 2.5 to 15.7% for shoulder strength conventional ratios and from 0.1 to 15.9% for dynamic control ratios. MDC_e(%) values ranged from 5.6 to 26.3% for conventional ratios and from 0.3 to 44% for dynamic control ratios. The CVs(%) ranged from 8.6 to 15.6% for shoulder strength indices, from 10.4 to 15.2% for shoulder strength conventional ratios, and from 10.8 to 17.8% for dynamic control ratios (Tables 1, 2).

Table 1
Reliability of the shoulder strength indices obtained during the isokinetic tests on Humac Norm dynamometer.

Parameters	Mean ± SD Measurement 1 (Nm)	Mean ± SD Measurement 2 (Nm)	Change in mean	Main effect *P*-value	$ICC_{(2,1)}$	95% CI Lower-Upper	Absolute Reliability SEM (%)	MDC (%)	SEM_e (%)	MDC_e (%)	CV (%)
FLisom at 45º	189.60 ± 36.54	194.73 ± 41.21	+5.13	0.288	0.94	0.83-0.98	5.0	13.7	7.3	20.3	14.3
EXisom at 45º	229.40 ± 35.17	238.33 ± 34.36	+8.93	0.098	0.91	0.75-0.97	4.5	12.4	10.5	29.0	10.5
FLisom at 90º	184.53 ± 29.48	185.27 ± 33.42	+0.74	0.869	0.92	0.77-0.97	4.8	13.3	1.1	3.0	12.0
EXisom at 90º	250.00 ± 41.82	256.47 ± 44.08	+6.47	0.151	0.96	0.89-0.99	3.4	9.4	7.0	19.4	12.0
FLisom at 135º	146.87 ± 22.38	151.87 ± 23.83	+5.00	0.289	0.83	0.50-0.94	6.4	17.7	9.2	25.4	10.9
EXisom at 135º	257.07 ± 51.28	252.13 ± 57.84	-4.94	0.465	0.94	0.83-0.98	5.2	14.5	5.3	14.7	15.2
FLcon at 60º/s	156.27 ± 27.89	159.53 ± 30.95	+3.26	0.434	0.92	0.77-0.97	5.3	14.6	5.7	15.7	13.2
EXcon at 60º/s	199.13 ± 24.63	201.13 ± 35.59	+2.00	0.740	0.84	0.52-0.95	6.2	17.1	2.7	7.6	10.9
FLcon at 180º/s	120.73 ± 23.80	131.53 ± 25.37	+10.80	0.008	0.92	0.75-0.97	5.5	15.3	23.4	65.0	13.8
EXcon at 180º/s	146.07 ± 24.69	155.93 ± 27.95	+9.86	0.011	0.94	0.81-0.98	4.3	11.8	17.9	49.6	12.3
FLcon at 300º/s	94.80 ± 19.94	99.80 ± 22.90	+5.00	0.074	0.94	0.83-0.98	5.4	14.9	14.1	39.0	15.6
EXcon at 300º/s	118.33 ± 24.72	126.47 ± 27.74	+8.14	0.008	0.96	0.88-0.99	4.3	11.9	18.2	50.4	15.2
FLecc at 60º/s	194.80 ± 30.54	194.40 ± 28.32	-0.40	0.955	0.73	0.20-0.91	7.9	21.8	0.6	1.6	10.7
EXecc at 60º/s	258.87 ± 43.99	265.80 ± 50.95	+6.93	0.428	0.86	0.60-0.95	6.9	19.1	7.2	20.1	13.0
FLecc at 180º/s	180.27 ± 22.18	183.80 ± 23.34	+3.53	0.503	0.76	0.29-0.92	6.3	17.4	5.3	14.7	9.1
EXecc at 180º/s	239.07 ± 23.85	248.67 ± 30.84	+9.60	0.143	0.77	0.31-0.92	5.9	16.2	10.8	29.9	8.6
FLecc at 300º/s	197.73 ± 31.13	204.40 ± 30.35	+6.67	0.243	0.87	0.60-0.96	5.5	15.3	9.1	25.2	10.8
EXecc at 300º/s	257.27 ± 34.20	276.27 ± 44.28	+19.00	0.008	0.90	0.70-0.97	5.0	13.8	17.6	48.8	11.1

Abbreviations: FL, flexion; EX, extension; isom, isometric; con, concentric; ecc, eccentric; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurements based on ICC; MDC, minimal detectable change based on ICC; SEM_e, standard error of measurements based on random error; MDC_e, minimal detectable change based on random error; CV, coefficient of variation.

Table 2

Reliability of the shoulder strength imbalance indices obtained during the isokinetic tests on Humac Norm dynamometer.

Parameters	Mean ± SD		Change in mean	Main effect *P*-value	$ICC_{(2,1)}$	95% CI Lower-Upper	Absolute Reliability				
	Measurement 1 (ratio)	Measurement 2 (ratio)					SEM (%)	MDC (%)	SEM_e (%)	MDC_e (%)	CV (%)
Conventional ratios											
FLisom/EXisom at 45º	0.84 ± 0.17	0.82 ± 0.15	-0.02	0.479	0.89	0.68-0.96	6.4	17.7	6.6	15.2	13.6
FLisom/EXisom at 90º	0.75 ± 0.14	0.73 ± 0.12	-0.02	0.331	0.91	0.73-0.97	5.3	14.6	7.4	15.2	12.4
FLisom/EXisom at 135º	0.59 ± 0.12	0.62 ± 0.13	+0.03	0.117	0.89	0.68-0.96	7.1	19.7	15.7	26.3	15.2
FLcon/EXcon at 60º/s	0.79 ± 0.11	0.80 ± 0.13	+0.01	0.431	0.92	0.73-0.97	4.3	11.9	5.3	11.6	10.7
FLcon/EXcon at 180º/s	0.83 ± 0.13	0.85 ± 0.14	+0.02	0.470	0.81	0.42-0.94	7.0	19.4	6.7	15.7	11.3
FLcon/EXcon at 300º/s	0.81 ± 0.11	0.80 ± 0.16	-0.01	0.787	0.83	0.49-0.94	6.9	19.1	2.5	5.6	11.8
FLecc/EXecc at 60º/s	0.76 ± 0.13	0.75 ± 0.12	-0.01	0.454	0.84	0.53-0.95	7.1	19.8	6.8	14.2	12.6
FLecc/EXecc at 180º/s	0.76 ± 0.10	0.74 ± 0.09	-0.02	0.256	0.93	0.80-0.98	3.9	10.7	5.3	11.1	10.4
FLecc/EXecc at 300º/s	0.78 ± 0.13	0.75 ± 0.12	-0.03	0.183	0.87	0.67-0.96	6.8	19.0	10.0	21.3	13.4
Dynamic ratios											
FLecc/EXcon at 60º/s	0.98 ± 0.15	0.98 ± 0.14	0.00	0.894	0.46	-0.62-0.82	11.2	31.1	0.1	0.3	10.8
FLecc/EXcon at 180º/s	1.27 ± 0.30	1.21 ± 0.24	-0.06	0.267	0.84	0.51-0.95	8.7	24.1	13.7	37.9	15.4
FLecc/EXcon at 300º/s	1.74 ± 0.49	1.67 ± 0.36	-0.07	0.489	0.85	0.64-0.96	9.8	27.0	10.6	29.3	17.8
EXecc/FLcon at 60º/s	1.69 ± 0.34	1.70 ± 0.33	+0.01	0.889	0.87	0.32-0.92	7.2	20.1	0.5	2.6	14.2
EXecc/FLcon at 180º/s	2.05 ± 0.42	1.93 ± 0.29	-0.12	0.211	0.74	0.33-0.92	10.0	27.7	15.9	44.0	13.9
EXecc/FLcon at 300º/s	2.80 ± 0.60	2.87 ± 0.67	+0.07	0.663	0.89	0.68-0.96	7.6	21.1	6.6	18.4	16.2

Abbreviations: FL, flexion; EX, extension; isom, isometric; con, concentric; ecc, eccentric; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurements based on ICC; MDC, minimal detectable change based on ICC; SEM_e, standard error of measurements based on random error; MDC_e, minimal detectable change based on random error; CV, coefficient of variation.

Tables 3 and 4 present the average of the differences between the two measurements (bias), the standard deviation of the measurements, the lower limit, the upper limit, and the confidence intervals (CI). Furthermore, Figure 2 shows indicative Bland-Altman percent plots with the bias line, the limits of agreement for the 2 measurements, and 95% confidence interval of the parameters showed the lower [FLcon at 180º/s; Figure 2(a)] and the higher [(FLecc at 60º/s; Figure 2(b) and FLecc/EXcon at 60º/s; Figure 2(c)] absolute reliability according to SEM_e(%) values.

Table 3
Bland and Altman plot statistics of the shoulder strength indices obtained during the isokinetic tests on Humac Norm dynamometer.

Parameters	Difference mean ($\bar{d}$)	SD(s)	95% CI of mean difference		95% CI of agreement limits			
			$\bar{d}$ - 1.96s	$\bar{d}$ + 1.96s	Lower limit From	Lower limit to	Upper limit From	Upper limit to
FLisom at 45º	-2.15	9.19	-20.16	15.86	-29.06	-11.26	6.96	24.75
EXisom at 45º	-3.92	8.58	-20.73	12.89	-29.03	-12.43	4.58	21.20
FLisom at 90º	-0.11	8.99	-17.72	17.50	-26.42	-9.02	8.80	26.20
EXisom at 90º	-2.51	6.49	-15.24	10.22	-21.52	-8.95	3.93	16.51
FLisom at 135º	-3.16	11.42	-25.54	19.22	-36.60	-14.48	8.16	30.28
EXisom at 135º	2.34	11.79	-20.57	25.64	-31.99	-9.15	14.22	37.06
FLcon at 60º/s	-1.69	10.50	-22.27	18.88	-32.43	-12.10	8.71	29.04
EXcon at 60º/s	-0.11	12.30	-24.22	24.00	-36.14	-12.39	12.09	35.91
FLcon at 180º/s	-8.66	11.76	-31.70	14.39	-43.08	-20.31	3.00	25.77
EXcon at 180º/s	-6.38	9.03	-24.08	11.31	-32.52	-15.34	2.57	20.05
FLcon at 300º/s	-4.92	9.61	-23.76	13.91	-33.25	-15.45	2.78	20.59
EXcon at 300º/s	-6.33	9.19	-24.35	11.69	-34.39	-14.95	4.95	24.39
FLecc at 60º/s	-0.06	13.36	-26.23	26.12	-39.16	-13.30	13.19	39.05
EXecc at 60º/s	-2.30	12.85	-27.48	22.89	-39.93	-15.04	10.45	35.34
FLecc at 180º/s	-1.88	10.83	-23.10	19.34	-33.59	-12.62	8.85	29.83
EXecc at 180º/s	-3.73	9.42	-22.20	14.73	-31.32	-13.07	5.61	23.85
FLecc at 300º/s	-3.50	9.79	-22.69	15.69	-22.17	-13.21	6.21	25.17
EXecc at 300º/s	-6.70	8.47	-23.30	9.91	-31.50	-15.09	1.71	18.12

Abbreviations: Difference mean ($\bar{d}$), the average of the differences between the two measurements (bias); SD(s), the standard deviation of the measurements; $\bar{d}$ - 1.96s, the lower limit; $\bar{d}$ + 1.96s, the upper limit; CI, Confidence Intervals.

Table 4
Bland and Altman plot statistics of the shoulder imbalance indices obtained during the isokinetic tests on Humac Norm dynamometer.

Parameters	Difference mean ($\bar{d}$)	SD(s)	95% CI of mean difference		95% CI of agreement limits			
			$\bar{d}$ - 1.96s	$\bar{d}$ + 1.96s	Lower limit		Upper limit	
					From	to	From	to
Conventional ratios								
FLisom/EXisom at 45º	1.76	11.88	-21.53	25.05	-33.04	-10.02	13.55	36.56
FLisom/EXisom at 90º	2.45	9.77	-16.70	21.60	-26.17	-7.24	12.13	31.06
FLisom/EXisom at 135º	-5.59	12.59	-30.26	19.10	-42.46	-18.07	6.90	31.29
FLcon/EXcon at 60º/s	-1.77	8.46	-18.35	14.80	-26.54	-10.16	6.61	22.99
FLcon/EXcon at 180º/	-2.30	13.11	-27.99	23.39	-40.63	-15.30	10.70	36.08
FLcon/EXcon at 300º/	1.78	13.17	-24.04	27.59	-36.79	-11.28	14.83	40.33
FLecc/EXecc at 60º/s	2.48	13.00	-23.00	27.96	-35.58	-10.41	15.37	40.55
FLecc/EXecc at 180º/s	1.91	6.17	-10.18	14.00	-16.16	-4.21	8.03	19.98
FLecc/EXecc at 300º/s	3.50	9.68	-15.26	22.47	-24.83	-6.09	13.10	31.84
Dynamic ratios								
FLecc/EXcon at 60º/s	-0.03	17.90	-35.11	35.05	-52.44	-17.78	17.72	52.39
FLecc/EXcon at 180º/s	4.47	15.22	-25.36	34.30	-40.10	-10.62	19.56	49.03
FLecc/EXcon at 300º/s	2.73	14.93	-26.54	31.99	-40.99	-12.08	17.53	46.45
EXecc/FLcon at 60º/s	-0.55	17.76	-35.36	34.26	-52.56	-18.16	17.08	51.46
EXecc/FLcon at 180º/s	4.98	14.70	-23.83	33.79	-38.07	-9.60	19.55	48.02
EXecc/FLcon at 300º/s	-1.71	14.86	-30.83	27.43	-45.22	-16.44	13.04	41.82

Abbreviations: Difference mean ($\bar{d}$), the average of the differences between the two measurements (bias); SD(s), the standard deviation of the measurements; $\bar{d}$ - 1.96s, the lower limit; $\bar{d}$ + 1.96s, the upper limit; CI, Confidence Intervals.

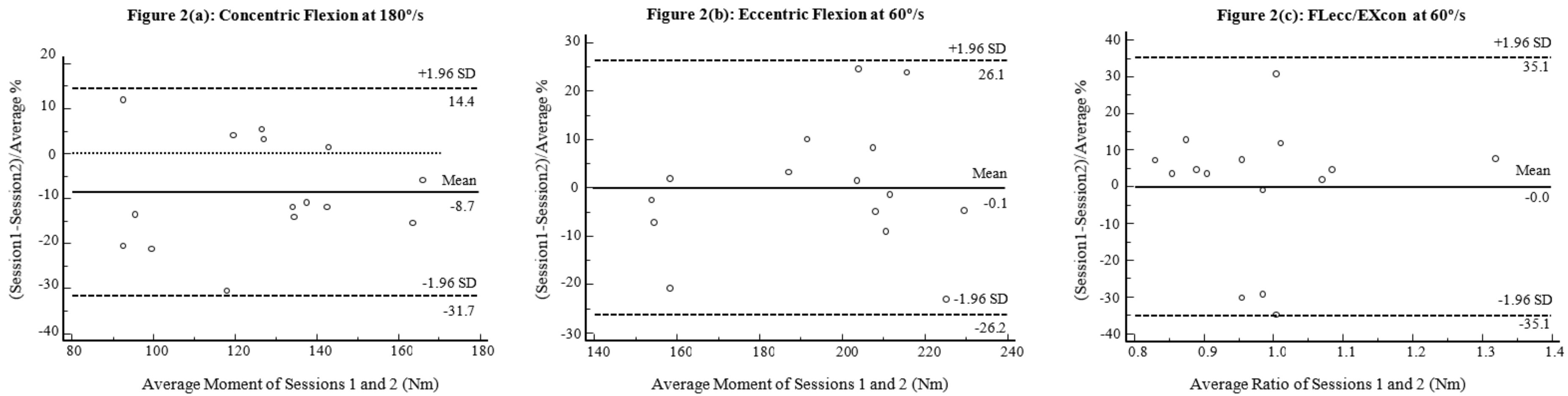

Figure 2. Bland-Altman plots of differences between session 1 and session 2, expressed as percentages of the values on the axis [(session 1-session 2)/average%)] against the mean of the two measurements. The bias line (mean absolute agreement), random error (upper and lower) and lines forming the 95% limits of agreement are presented on the plot.

According to the Bland-Altman analysis, PM showed mean of differences of less than 10%. The mean of differences (bias) for PM was non-significant at session 1 and 2. Furthermore, the LOAs were low (LOAs < 28%) for the majority of the variables. However, the LOAs were higher (LOAs < 35%), for the variables Flcon at 180º/s, FLisom/EXisom at 135º/s, FLcon/EXcon at 60º/s, FLcon/EXcon at 180º/s, FLcon/EXcon at 300º/s, EXecc/FLcon at 60º/s, EXecc/FLcon at 180º/s, and EXecc/FLcon at 300º/s.

DISCUSSION

The present study analyzed the relative and absolute reliability of international level gymnasts' isometric and isokinetic shoulder flexion and extension PM and conventional and dynamic control ratios. The main findings of this study were: (a) the PM and ratios values were comparable with those presented in the literature, (b) the relative and absolute reliability for both shoulder PM and conventional and dynamic control ratios was acceptable to excellent, showing critical results for only a few measurements as evaluated by SEM_e(%) and MDC_e(%).

In the present study, systematic bias was detected only for the parameters FLcon and EXcon at 180º/s, EXcon at 300º/s, and EXecc at 300º/s. Atkinson and Nevill (1998) supported that there might be a trend for a retest to be higher than a prior test due to a learning effect. It could be supported that subjects of the present study as novices in isokinetic measurements, familiarized much easier with the isometric and isokinetic contractions in low and moderate (eccentric) angular velocities, after the practicing trials according to the adapted protocol. Conversely, the systematic error detected in the present study may be explained by the participants' familiarization (learning effect) of the measurements in high angular velocities after the completion of the first measurement (more trials). Therefore, for high angular velocities, it is recommended to design a measurement protocol that removes the learning effect from the test. For example, it could include more familiarization trials before the implementation of the measurement, increase the time between repeated measurements (Baumgarter, 1989), or perform more measurements (re-tests) (Atkinson & Nevill, 1998; Streiner & Norman, 1996).

Isometric and isokinetic (concentric and eccentric) shoulder PM values measured in the present study were comparable to the measurements of other studies (Cahalan, Johnson, & Chao, 1991), considering the differences in the design of the studies (e.g., protocol, participants). In the present study, the isometric flexion PM decreased as the angle increased (45º, 90º, 135º), while the opposite occurred for the extension PM. In agreement with previous research findings (Bassa, Michailidis, Kotzamanidis, Siatras, & Chatzikotoulas, 2002; Cahalan et al., 1991; Mameletzi, Siatras, Tsalis, & Kellis, 2003), isokinetic concentric flexion and extension PM values decreased as angular velocity increased. Conversely the isokinetic eccentric PM values decreased at 180º/s compared to the values at 60º/s, and increased at 300º/s compared to the values at 60º/s and at 180º/s, partially confirming the notion that as angular velocity increases the eccentric force remains the same or increases (Bassa et al., 2002; Greenfield, Donatelli, Wooden, & Wilkes, 1990). Conventional ratios values for the isometric shoulder strength decreased as the angle increased, while they were almost stable for the isokinetic contraction for the three different angular velocities. Finally, in agreement with the findings of other studies (Scoville, Arciero, Taylor, & Stoneman, 1990), values for the dynamic control ratios increased as angular velocity increased, for both the FLecc/EXcon and the EXecc/FLcon.

It has been supported that due to their greater muscle mass, the shoulder extensors would be expected to produce greater moment than the shoulder flexors muscles (Cahalan et al., 1991; Cook, Gray, Savinar-Nogue, & Medeiros, 1987; Siatras et al., 2010; Zhou et al., 2014). Previous investigations showed conventional ratios of 0.80 for normal volunteers (Ivey, Calhoun, Rusche, & Bierschenk, 1985), 0.70 to 0.81 for pitchers and 0.76 to 0.99 for non-pitchers (Cook et al., 1987) and 0.75 to 0.80 for adult tennis players (Ellenbecker, 1991). Considering the differences that existed in the design of the studies, the shoulder conventional ratios estimated in the present study are in line with those reported above (isometric 0.59 to 0.84, isokinetic concentric 0.75 to 0.85, and isokinetic eccentric 0.74 to 0.78). Based on these findings it could be concluded that highly competitive gymnasts do not have muscle imbalances regarding the shoulder flexors' and extensors' strength. However, some studies found lower conventional ratios as for example 0.48 for high school and college-aged pitchers (Alderink & Kuck, 1986), 0.63 for high school wrestlers (Housh et al., 1990), and 0.46 to 0.53 for normal volunteers varying by age (Hughes, Johnson, O'Driscoll, & Kai-Nan An, 1999), indicating some disagreement among these investigations. However, reviewing the literature no research data have been found regarding the gymnasts' shoulder dynamic control ratios. The results of the present study provided novel data for these parameters.

In the present study, results from ICC measurements showed strong reproducibility of shoulder flexion and extension at all angles and angular velocities in line with results from previews studies (Atkinson & Nevill, 1998; Cools et al., 2002; Hopkins, 2000). Correspondingly, ICC values for shoulder strength conventional ratios were considered moderate in 6 cases, and high in 3 cases and as for dynamic control ratios they were considered low in one case and moderate in 4 cases. Researchers have reported low reliability for muscle balance ratios and they suggested that shoulder strength assessments are more reliable when they are based on measurements of PM (Nm) than when based on balance ratios (%) (e.g., Codine, Bernard, Sablayrolles, & Herrison, 2005). The lower reliability for the evaluation of strength ratios compared to the PM values, it is probably due to the fact that they are a composite of two absolute scores, each possibly varying in the same or a different direction with re-evaluation, resulting in error reproduction (Iga, George, Lees, & Reilly, 2006). In the present study, a low ICC compared to all other ICCs was presented only for the dynamic ratio FLecc/EXcon at 60º/s. This result could be attributed to the low levels of between-subjects variability for this parameter, which according to Atkinson and Nevill (1998) depress the ICC even if the differences between subjects' scores across test conditions are small. It is becoming clear that the use of ICCs only, for the analyses of reliability is not sufficient because they influenced by the between-subject variability and the heterogeneity of the sample (Atkinson & Nevill, 1998; Hopkins, 2000). Thus, although the test for reliability of tools and protocols for the measurement of isokinetic muscle strength with correlation methods showed strong reproducibility (Perrin, 1993), it has been supported that the repeatability of these measurements is relatively poor at faster isokinetic angular velocities (Atkinson, Greeves, Reilly, & Cable, 1995). By examining the reliability of 23 common measurement tools in sport and exercise science research, Nevill and Atkinson (1997) found that using an absolute measurement of reliability emerged considerable differences in reliability between measurement tools. These notions were confirmed in the present study in which relative and different absolute measurements of reliability were used. For example, while the ICCs for the parameters FLcon and EXcon at 180º/s, EXcon at 300º/s, and EXecc at 300º/s (in which systematic bias was detected) showed strong reliability, the absolute reliability indices (with the exception of SEM based on ICC) were indicators of low reliability.

Furthermore, SEM(%) and MDC(%) based on the ICC showed high reliability for all shoulder strength and imbalance measurements according to the recommendations of Lund et al. (2005). However, there was a disagreement in some cases with the SEM_e(%) and MDC_e(%) indices in which the reliability was not strongly supported (e.g., for the parameters FLcon and EXcon at 180º/s, EXcon at 300º/s, and EXecc at 300º/s in which systematic bias was detected). On the other hand, CV(%) values with an analytical goal of 15% or below were considered as acceptable for almost all the parameters. These findings provide support to the arguments of Lund et al. (2005) and Atkinson and Nevill (1998) that the interpretation of the reliability of a measurement is a complex procedure and the acceptance of the reliability levels for a specific measurement depends on the analytical goals.

According to their review of literature, Edouard et al. (2011) reported that PM isokinetic strength parameters seem to present a moderate-high absolute reliability (SEM < 10%). This tendency was present regardless of the muscle contraction (concentric and eccentric), angular velocity (low, moderate and high) and joint movement (knee flexion and extension). On the other hand, Ayala et al. (2013) based on their review, reported that concentric muscle contraction presents lower intersession variability, compared to eccentric contraction (5.9 and 10.4% of SEM for concentric and eccentric contractions, respectively). In addition, the same review does not support the notion that higher angular velocities generate higher variability if the results are obtained in comparison to low and moderate velocities (low: 7.7% SEM; moderate: 8.6% SEM; and high: 8.2% SEM). However, it is important to take into account that these studies concerned mainly low to moderate angular velocities for the joint of the knee. Another important factor which must be taken into account is the type of absolute reliability index used.

Compared to the above findings, the results of the present study provided some trends (not so clear in some cases) for the intersession variability of the measurements of isometric and isokinetic shoulder strength parameters based mainly on the SEM_e(%) and MDC_e(%) indices: (a) isometric contractions and their conventional ratios presented lower intersession variability at the moderate angle (90º), (b) the intersession variability of isokinetic contractions presented to be lower at the angular velocity of 60º/s, while conventional ratios for concentric contractions presented lower intersession variability at the angular velocity of 300º/s and at the angular velocity of 180º/s for eccentric contractions (c) the intersession variability of flexion contractions were presented to be lower compared to extension contractions; and (d) dynamic control ratios (FLecc/EXcon and EXecc/FLcon) presented lower intersession variability at the angular velocity of 60º/s (Tables 1 and 2).

Results from the Bland-Altman analysis of the present study provided support for the equivalence of the two measurements (Tables 3 and 4; Figure 1). More specifically, the average discrepancy between the two measurements (the bias) was small and not statistically significant in all cases and the LOAs were narrow in most cases. This finding was in line with that of previous studies of isokinetic dynamometry. Reviewing the literature, Ayala et al. (2013) reported that the PM strength parameter presents a value of variability that range from 5.9% to 33.0%.

The present study had some limitations. In this study, specific shoulder strength parameters of fifteen highly competitive male gymnasts having some interpersonal variability as regards their personal characteristics (e.g., age, weight, competitive level) of one mid-sized city, were tested by one investigator. Although the size of the sample is considered adequate for the evaluation of reliability, and statistical analyses confirmed the normality of the data and the homogeneity of variance between the two measurements, larger sample sizes have been suggested by some researchers to form a practically useful 95% MDC and MDC(%) and LOAs

(Hopkins, 2000). Furthermore, a small systematic bias demonstrated an increase in four parameters from measurement 1 to measurement 2, was observed in the present study.

Therefore, extreme care should be taken before extending the inference of this study. More research is needed to develop more sensitive assessment methods to evaluate the training efficacy oriented towards the improvement of the shoulder force in gymnastics. A more extensively familiarizing procedure and additional investigators should be included in further evaluations in order to increase the generalizability of such results. Furthermore, it is suggested to evaluate the reliability of other aspects of strength except PM (e.g., time to PM, total work, power) and other movements of the shoulder joint (e.g., external, internal rotation), in a larger sample of gymnastics athletes and non-athletes, using relative measures (e.g., PM/body weight) in order to eliminate the possible effects of interpersonal variability. By examining and validating the relationships between these parameters, sufficient evidence to support extrapolation of the data at different test protocols for different sports, physical, and daily activities could be provided.

The evaluation of the absolute reliability of these parameters relevant to gymnastics movements and performance provided ecological validity to the results of the present study. Specifically, gymnastics trainers could use the assessment methods suggested above and the normative data provided by such methods to evaluate the improvement of shoulder flexion and extension strength after the implementations of training programs or the deterioration over time. Furthermore, such reliable measurements could provide information about the progress of gymnasts over time and could be useful for guiding the training for the achievement of difficult gymnastics skills as for example (a) static elements (e.g., "Hanging scale", "Manna", "Support lever", "Swallow"), (b) strength elements (e.g., "Press to handstand with bend or straight body and straight arms", "From hanging scale rear ways press to swallow or to support scale"), and (c) elements which require rapid flexion or extension of shoulder (e.g., "Salto backwards stretched", "Scissor to handstand", "Back kip to support scale at ring height", "Forward handspring", "Basket to handstand").

CONCLUSION

Considering the limitations of the present study, the results supported the reliability of the shoulder flexion and extension measurements for different contraction modes, angles and angular velocities. All the indices used in the study (relative and absolute) provided acceptable reproducibility of the measurements and seem to be appropriate if there is a need for a detection of large strength differences (e.g., elite athletes vs. non-athletes, males vs. females, adult vs. adolescents, after rehabilitation programmes). However, to detect any significant change between two measurements for elite athletes or for the same athlete after the implementation of different strength training programmes, or to detect muscle imbalances, SEM_e(%) and MDC_e(%) are more important and meaningful. Furthermore, in order to eliminate differences due to interpersonal variability of the participants, the use of relative measures (e.g., PM/body weight) instead of PM is suggested. Future studies, using the methods provided above should examine the relationships of objective and dynamic control shoulder strength values with the performance of gymnasts in difficult gymnastics skills as described above.

The present study contributed to the establishment of normative data, to determine a functional-strength profile of the shoulder flexion and extension muscles for highly competitive gymnasts, for isometric (in specific angles) and isokinetic concentric and eccentric (in low, moderate, and high angular velocities) contractions. Furthermore, the results of the present study could also be very helpful for practitioners (e.g., trainers, therapists) and researchers of the physical activity, sports, exercises and daily activities or jobs requiring bilateral hand coordination, since it could reflect objective and dynamic control shoulder strength values. Considering the limitations of the study, such measurements could be very useful to detect important changes after interventions or deterioration over time. Moreover, although the balance of flexibility and strength of the rotator cuff muscles play the central role in the stability of the shoulder joint, proper balance of the muscles which act in shoulder flexion and extension as for example pectoralis major and deltoid is also necessary for the good function of the shoulder and the prevention of injury.

REFERENCES

Aagaard, P., Simonsen, E. B., Magnusson, S. P., Larsson, B., & Dyhre-Poulsen, P. (1998). A new concept for isokinetic hamstring: Quadriceps muscle strength ratio. *American Journal of Sports Medicine, 26,* 231-237. doi: 10.1177/03635465980260021201

Alderink, G. J., & Kuck, D. J. (1986). Isokinetic shoulder strength of high school and college-aged pitchers. *Journal of Orthopedic Sports Physical Therapy, 7,* 163-172. doi: 10.2519/jospt.1986.7.4.163

Atkinson, G., Greeves, J., Reilly, T., & Cable, N. T. (1995). Day-to-day and circadian variability of leg strength measured with the LIDO isokinetic dynamometer. *Journal of Sports Sciences, 13,* 18-19.

Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine, 26,* 217-238. doi: 10.2165/00007256-199826040-00002

Ayala, F., Sainz de Baranda, P., De Ste Croix, M., & Santonja, F. (2013). Absolute reliability of isokinetic measurement for estimating muscle function. *Revista Multidisciplinar de las Ciencias del Deporte, 13*(52), 799-830.

Bak, K., & Magnusson, D. P. (1997). Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *American Journal of Sports Medicine, 25,* 454-459.

Bassa, H., Michailidis, H., Kotzamanidis, Ch., Siatras, Th., & Chatzikotoulas, K. (2002). Concentric and eccentric isokinetic knee torque in pre-pubescent male gymnasts. *Journal of Human Movement Studies, 42,* 213-227.

Baumgarter, T. A. (1989). Norm-referenced measurement: reliability. In: Safrit, M. J., Wood, T. M. (Ed.). *Measurement concepts in physical education and exercise science* (pp. 45-72). Champaign (IL): Human Kinetics.

Bland, J. M., & Altman, D. G. (1996). Measurement error proportional to the mean. *British Medical Journal, 313*(7049), 106.

Cahalan, T. D., Johnson, M. E., & Chao, E. Y. S. (1991). Shoulder strength analysis using the Cybex II. *Clinical Orthopaedics and Related Research, 271,* 249-257. doi: 10.1097/00003086-199110000-00034

Caine, D. J. (2003). Injury epidemiology. In W.A. Sands, D.J. Caine, & J. Borms (Eds.), *Scientific Aspects of Women's Gymnastics, Medicine and Sports Science,* (pp. 72-104). Basel, Switzerland: Karger.

Codine, P., Bernard, P. L., Sablayrolles, P., & Herrison, C. (2005). Reproducibility of isokinetic shoulder testing. *Isokinetics and Exercise Science, 13,* 61-62.

Cook, E. E., Gray, V. L., Savinar-Nogue, E., & Medeiros, J. (1987). Shoulder antagonistic strength ratios: a comparison between college-level baseball pitchers and nonpitchers. *Journal of Orthopaedic and Sports Physical Therapy, 8,* 451-461. doi: 10.2519/jospt.1987.8.9.451

Cools, A. M., Geerooms, E., Van den Berghe, D. F., Cambier, D. C., & Witvrouw, E. E. (2007). Isokinetic scapular muscle performance in young elite gymnasts. *Journal of Athletic Training, 42*(4), 458-463.

Computer Sports Medicine, Inc. (CSMI). (2006). *Humac®/Norm™ testing & rehabilitation system user's guide model 770*. Stoughton, MA: Computer Sports Medicine, Inc.

Edouard, P., Samozino, P., Julia, M., Gleizes Cervera, S., Vanbiervliet, W., Calmels, P., & Gremeaux, V. (2011). Reliability of isokinetic assessment of shoulder-rotator strength: A systematic review of the effect of position. *Journal of Sports Rehabilitation, 20,* 367-383. doi: 10.1123/jsr.20.3.367

Ellenbecker, T. S. (1991). A total arm strength isokinetic profile of highly skilled tennis players. *Isokinetics and Exercise Science, 1,* 9-21. doi: 10.1016/0021-9290(89)90193-0

Fetz, C. J., & Miller, G. E. (1996). An asymptotic test for the equality of coefficients of variation from k populations. *Statistics in Medicine, 15*(6), 646-658. doi: 10.1002/(SICI)1097-0258(19960330)15:6<647::AID-SIM184>3.0.CO;2-P

Greenfield, B. H., Donatelli, R., Wooden, M. J., & Wilkes, J. (1990). Isokinetic evaluation of shoulder rotational strength between the plane of scapula and the frontal plane. *The American Journal of Sports Medicine, 18,* 124-128. doi: 10.1177/036354659001800202

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30,* 1-15. doi: 10.2165/00007256-200030010-00001

Housh, T. I., Hughes, R. I., Johnson, G. O., Housh, D. I., Wagner, L. L., Weir, J. P., & Evans, S. A. (1990). Age-related increases in the shoulder strength of high school wrestlers. *Pediatric Exercise Science, 2,* 65-72. doi: 10.1123/pes.2.1.65

Hughes, R. E., Johnson, M. E., O'Driscoll, S. W., & An, K. N. (1999). Normative values of agonist-antagonist shoulder strength ratios of adults aged 20-78 years. *Archives of Physical Medicine and Rehabilitation, 80,* 1324-1326. doi:10.1016/S0003-9993(99)90037-0

Iga, J., George, K., Lees, A., & Reilly, T. (2006). Reliability of assessing indices of isokinetic leg strength in pubertal soccer players. *Pediatric Exercise Science, 18,* 436-445. doi: 10.1123/pes.18.4.436

Impellizzeri, F. M., Bizzini, M., Rampinini, E., Cereda, F., & Maffiuletti, N. A. (2008). Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. *Clinical Physiology and Functional Imaging, 28,* 113-119. doi: 10.1111/j.1475-097X.2007.00786.x

Ivey, P. M., Calhoun, J. H., Rusche, K., & Bierschenk, J. (1985). Isokinetic testing of shoulder strength: normal values. *Archives of Physical Medicine and Rehabilitation, 66,* 384-386. doi: 10.1249/00005768-198404000-00108

Lund, H., Søndergaard, K., Zachariassen, T., Christensen, R., Bülow, P., Henriksen, M.,…Bliddal, *H.* (2005). Learning effect of isokinetic measurements in healthy subjects, and reliability and comparability of biodex and lido dynamometers. *Clinical Physiology and Functional Imaging, 25*(2), 75-82. doi: 10.1111/j.1475-097X.2004.00593.x

Maffiuletti, N. A., Bizzini, M., Desbrosses, K., Babault, N., & Munzinge, U. (2007). Reliability of knee extension and flexion measurements using the Con-Trex isokinetic dynamometer. *Clinical Physiology and Functional Imaging, 27*(6), 346-353. doi: 10.1111/j.1475-097X.2007.00758.x

Mameletzi, D., Siatras, Th., Tsalis, G., & Kellis, S. (2003). The relationship between lean body mass and isokinetic peak torque of knee extensors and flexors in young male and female swimmers. *Isokinetics and Exercise Science, 11*(3), 159-163.

Mayer, F., Horstmann, T., Baurle, W., Gray, S., Handel, M., & Dickhuth, H. H. (2001). Diagnostics with isokinetic devices in shoulder measurements-potentials and limits. *Isokinetics and Exercise Science 9,* 19–25.

McMaster, W. C., Long, S. C., & Caiozzo, V. J. (1991). Isokinetic torque imbalance in the rotator cuff of the elite water polo player. *The American Journal of*

Sports Medicine, 19, 72-75. doi: 10.1177/036354659101900112

Mikesky, A. E., Edwards, J. E., Wigglesworth, J. K. & Kunkel, S. (1995). Eccentric and concentric strength of the shoulder and arm musculature in collegiate baseball pitchers. *The American Journal of Sports Medicine*, *23*(5), 638-642.

Moudgil R., & Karpovich, P. V. (1969). Duration of a maximal isometric muscular contraction. *Research Quarterly for Exercise and Sport, 40*, 536-539.

Nevill, A. N., & Atkinson, G. (1997). Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. *British Journal of Sports Medicine, 31*, 314-318. doi:10.1136/bjsm.31.4.314

Perrin, D. H. (1993). *Isokinetic exercise and assessment*. Champaign (IL): Human Kinetics.

Plotnikoff, N. A., & MacIntyre, D. L. (2002). Test-retest reliability of glenohumeral internal and external rotator strength. *Clinical Journal of Sport Medicine, 12,* 367-372. doi: 10.1097/00042752-200211000-00008

Portney, L., & Watkins, M. (2000). *Foundations of clinical research: applications to practice*. Upper Saddle River, NJ: Prentice Hall.

Scoville, C. R., Arciero, R. A., Taylor, D. C., & Stoneman, P. D. (1997). End range eccentric antagonist/concentric agonist strength ratios: a new perspective in shoulder strength assessment. *Journal of Orthophedic Sports Physical Therapy, 25*(3), 203-207. doi: 10.2519/jospt.1997.25.3.203

Siatras, Th., Douka, I., & Milosis, D. (2010). Feasibility and reproducibility of muscular strength measures in gymnastics-specific body positions using hand-held dynamometry. *Isokinetics and Exercise Science*, *18*(4), 223-234. doi: 10.3233/IES-2010-0388

Streiner, D. L., & Norman, G. R. (1996). *Health measurement scales. A practical guide to their development and use* (2nd ed.). Oxford: Oxford Medical Publications.

Thomas, J. R., & Nelson, J. K. (1990). *Introduction to research in health, physical education, recreation and dance* (2nd ed). Champaign (IL): Human Kinetics.

Walmsley, R. P., & Pentland, W. (1993). An overview of isokinetic dynamometry with specific reference to the upper limb. *Clinical Rehabilitation, 7,* 239-247. doi: 10.1177/026921559300700310

Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength and Conditioning Research,* *19*(1), 231-240. doi: 10.1519/15184.1

Yildiz, Y., Aydin, T., Sekir, U., Kiralp, M. Z., Hazneci, B., & Kalyon, T. A. (2006). Shoulder terminal range eccentric antagonist/concentric agonist strength ratios in overhead athletes. *Scandinavian Journal of Medicine and Science in Sports*, *16*(3), 174-180. doi: 10.1111/j.1600-0838.2005.00471.x

Zhou, J. H., Liu, Y., Cheng, L., & Jiang, Y-F. (2014). Research of shoulder isokinetic power test of excellent gymnasts. In W-P. Sung, J. C. M. Kao, & R .Chen (Eds.), *Environment, Energy and Sustainable Development*, (pp. 627-629). London: Taylor & Francis Group.

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