Sports **2015**, *3*, 236-245; doi:10.3390/sports3030236

OPEN ACCESS

sports

ISSN 2075-4663

www.mdpi.com/journal/sports

Article

Angle Specific Analysis of Side-to-Side Asymmetry in the Shoulder Rotators

Cassio V. Ruas [1,*], Ronei S. Pinto [1,†], Eduardo L. Cadore [1,†] and Lee E. Brown [2]

[1] Physical Education School, Federal University of Rio Grande do Sul, Brazil, Felizardo Street, 750—Jardim Botânico, Porto Alegre/RS 90690-200, Brazil; E-Mails: ronei.pinto@ufrgs.br (R.S.P.); cadoreeduardo@gmail.com (E.L.C.)

[2] Department of Kinesiology, KHS 233 800 N. State College Blvd., California State University, Fullerton 92831, CA, USA; E-Mail: leebrown@fullerton.edu

† These authors contributed equally to this work.

* Author to whom correspondence should be addressed; E-Mail: cassiovruas@gmail.com; Tel.: +55-513-308-5894; Fax: +55-513-308-5843.

Academic Editor: Eling de Bruin

Received: 16 July 2015 / Accepted: 27 August 2015 / Published: 31 August 2015

Abstract: Although side-to-side asymmetry of the shoulder rotators calculated by independent peak torque (IPT) has been used for interpretation of injury risks in athletes, it may not measure strength through the entire range of motion (ROM) tested. The aim of this study was to compare side-to-side asymmetry of the shoulder rotators between independent peak torque (IPT) and ten-degree angle specific torque (AST). Twenty healthy adult males (24.65 ± 2.4 years) performed concentric and eccentric internal rotation (IR) and external rotation (ER) of the preferred and non-preferred arms on an isokinetic dynamometer at 60°/s through 150° of total ROM. The total ROM was divided into 14 ten-degree angles of the physiological ROM from −90° of ER to 60° of IR. Concentric and eccentric IR IPT (10.5% ± 8.7% and 12.1% ± 7.2%) and ER IPT (13.6% ± 9.8% and 8.7% ± 5.6%) were significantly less than AST at several angles ($p < 0.05$). IPT might lead to erroneous interpretations of side-to-side asymmetry in the shoulder rotators and does not represent the entire ROM tested. This information could be used to prescribe strength exercises to enhance overhead performance and reduce risk of shoulder injuries.

Keywords: angle specific torque; independent peak torque; strength imbalance; injury prevention; performance enhancement

1. Introduction

The shoulder rotator muscles are important for coordinated performance of overhead activities, such as pitching in baseball, swinging a racket in tennis or pushing against the water in swimming [1–3]. Forceful and repetitive actions in overhead sports have been associated with an increased susceptibility of shoulder rotator injuries [3,4], strength differences between external (antagonists) and internal rotator (agonists) muscles [1,3–5], and side-to-side differences between upper-limbs [2,5]. Typical shoulder strength asymmetry has been reported as an upper-limb dominance of 5%–10% measured by independent peak torque (IPT) in nonathletic and recreational-level athletes [5]. However, these IPT measurements fail to reproduce the functionality of muscles during sporting activities, because torque is not calculated through the entire range of motion (ROM), or at corresponding angles [1,6,7].

2. Context

A previous investigation has demonstrated that this can lead to misinterpretation of strength imbalance of the shoulder rotators [1]. In addition, a few studies have opted to use 5°, 10°, 15° or end of ROM angle specific torque (AST) intervals for a more accurate estimation of unilateral dynamic muscle balance of the knee or shoulder joints [1,3,4,6–9]. Dehail *et al.* [7] demonstrated there was a significant progressive decline of flexion/extension and abduction/adduction AST strength ratios as the shoulder progressed to flexion and abduction, respectively. Yildiz *et al.* [4], found that although internal rotator eccentric strength of the preferred side was greater than the non-preferred side at the end of the ROM, only the internal rotator concentric strength was greater than the non-preferred side at the beginning of the ROM. Although IPT evaluations may be more sensitive to assess muscle strength balance changes after strength rehabilitation programs [10], AST analysis has been shown to be a more appropriate tool to precisely locate potential muscle imbalances present at specific joint angles [1,6,7]. This information may be used for the prescription of strength exercises of the weak angles.

Although AST analysis has been used to measure unilateral imbalance, there is a lack of information using this approach to measure side-to-side asymmetry of the shoulder rotators. Thus, the aim of this study was to compare side-to-side asymmetry of the internal and external shoulder rotators between traditional IPT and ten-degree AST methods.

3. Method

3.1. Participants

Twenty healthy adult males (age 24.6 ± 2.4 years, body mass 81.6 ± 15.5 kg, height 175.3 ± 8.0 cm) volunteered to participate in this study. All of them participated in recreational activities (e.g., basketball, jogging, resistance training) at least once a week, and had no history of shoulder injuries in the previous six months prior to testing. Their body mass was measured using a digital scale (Model # ES200L, Ohaus, Pine Brook, NJ, USA), and height using a wall-mounted stadiometer (Seca Stadiometer, ON, Canada). All participants read and signed an informed consent form prior to participation. The study was approved by the University Institutional Review Board (HSR#130126), and the rights of the subjects were protected.

3.2. Experimental Design

Prior to testing, participants were asked about their preferred arm when throwing an object (dominance) [2]. To examine their torque capabilities, concentric isokinetic tests were performed for the internal and external shoulder rotators of the preferred and non-preferred arms. Side-to-side torque asymmetry was calculated based on these results.

3.3. Experimental Procedures

Maximal internal and external rotator concentric and eccentric strength was measured on a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA). Participants laid supine on the dynamometer with straps across their chest and hips to avoid additional movement. Participants grasped the lever arm of the machine and their tested arm was positioned at 90° of shoulder abduction and 90° of elbow flexion with their forearm in a neutral position in the coronal plane for alignment with the dynamometer's axis of rotation [1,11]. This position was considered 0°. Both preferred and non-preferred arms were tested.

Shoulder rotator strength was measured through 150° of total ROM, from 90° ER (−90°) to 60° IR of physiologic ROM. This ROM was chosen as it was uncomfortable for subjects to perform maximal strength beyond these limits in a pilot study. Prior to testing, participants performed a warm up of 5 submaximal repetitions at 180°/s and 3 maximal repetitions at the test speed of 60°/s for familiarization purposes. Testing consisted of 5 reciprocal concentric/concentric and 5 eccentric/eccentric maximal repetitions, with 3 min rest between modes. Preferred and non-preferred arms were assessed in random order. Participants were asked to push and pull as hard and fast as possible and verbal encouragement was provided during the test.

3.4. Outcome Measures

Maximal concentric and eccentric internal rotation (IR) and external rotation (ER) independent peak torque (IPT) were measured, as well as the angles of IPT (AIPT).

All data were collected and analyzed using custom LabVIEW Software (version 2013, National Instruments, Austin, TX, USA) and was divided into 14 ten-degree AST from −90° ER to 60° IR of physiological ROM. Side-to-side asymmetry of the shoulder rotators for both IPT and AST were calculated as the percentage differences between the peak torque of the preferred and non-preferred arms.

3.5. Statistical Analyses

Four (IR and ER) 1 × 14 repeated measures ANOVAs were used to compare concentric and eccentric percentage differences between IPT and AST between arms. The effect size for each significant difference was calculated by using means (M) and standard deviations (SD) between variables to identify the magnitude and direction of the differences ($d = M_{AST} - M_{IPT}/SD_{IPT}$), in which values <0.35 were considered trivial, 0.35–0.80 small, 0.80–1.50 moderate, and >1.50 large for recreationally trained subjects [12]. All analyses were performed with SPSS version 20 (Statistical Package for Social Sciences, Chicago, IL, USA). An *a-priori* alpha level of 0.05 determined statistical significance.

4. Results

Means of concentric and eccentric IPT and AIPT of IR and ER of the preferred and non-preferred arms are presented in Table 1. Means of concentric and eccentric ten-to-ten-degree absolute AST of internal rotation (IR) and external rotation (ER) of the preferred and non-preferred arms (Table 2).

Table 1. Means ± SD of concentric and eccentric independent peak torque (IPT) and angles of independent peak torque (AIPT) of internal rotation (IR) and external rotation (ER) of the preferred and non-preferred arms.

Action	Concentric				Eccentric			
	IPT (N.m)		AIPT (°)		IPT (N.m)		AIPT (°)	
	Preferred	Non-preferred	Preferred	Non-preferred	Preferred	Non-preferred	Preferred	Non-preferred
IR	46.5 ± 16.6	44.3 ± 14.1	−35.6 ± 34.6	−33.2 ± 40.2	58.1 ± 21.0	56.9 ± 17.2	−40.9 ± 24.5	−16.3 ± 29.7
ER	42.7 ± 13.7	39.9 ± 12.1	0.7 ± 35.4	0.7 ± 31.8	52.5 ± 13.8	53.6 ± 15.1	−30.8 ± 10.8	−26.6 ± 13.9

Table 2. Means ± SD of concentric and eccentric absolute ten-to-ten-degree angle specific torque (AST) of internal rotation (IR) and external rotation (ER) of the preferred and non-preferred arms.

Angle (°)	Concentric		Eccentric	
	AST (N.m)		AST (N.m)	
	Preferred	Non-Preferred	Preferred	Non-Preferred
IR-80	38.2 ± 18.7	34.1 ± 13.0	34.4 ± 23.1	23.9 ± 24.8
IR-70	39.8 ± 17.5	37.4 ± 15.1	41.0 ± 21.2	31.3 ± 21.7
IR-60	40.9 ± 16.9	38.2 ± 15.9	47.0 ± 20.9	38.0 ± 18.8
IR-50	41.7 ± 16.8	38.0 ± 15.5	50.0 ± 20.3	45.2 ± 17.9
IR-40	41.7 ± 16.8	36.8 ± 15.0	50.9 ± 19.1	47.3 ± 18.4
IR-30	41.2 ± 15.4	37.4 ± 15.4	51.2 ± 18.5	49.6 ± 17.6
IR-20	39.6 ± 13.6	36.5 ± 14.1	50.7 ± 16.7	50.5 ± 17.3
IR-10	37.3 ± 12.1	36.6 ± 13.5	49.9 ± 15.8	50.5 ± 15.7
IR0	36.6 ± 11.6	36.8 ± 13.6	47.4 ± 16.1	50.2 ± 15.7
IR10	35.6 ± 10.7	36.3 ± 13.0	44.0 ± 15.0	49.1 ± 15.5
IR20	34.7 ± 9.9	35.8 ± 13.2	39.8 ± 14.4	47.1 ± 15.9
IR30	32.9 ± 8.9	34.9 ± 13.2	33.8 ± 14.7	42.7 ± 17.9
IR40	30.7 ± 8.5	34.0 ± 13.3	25.7 ± 14.9	35.7 ± 16.6
IR50	27.1 ± 9.1	32.3 ± 13.2	19.5 ± 11.6	24.9 ± 15.4
ER50	33.9 ± 15.1	32.8 ± 13.0	18.9 ± 14.0	19.0 ± 18.9
ER40	36.9 ± 16.2	35.2 ± 13.9	24.8 ± 17.3	27.6 ± 18.9
ER30	37.5 ± 16.0	35.7 ± 14.0	29.9 ± 17.3	33.7 ± 17.7
ER20	38.0 ± 15.2	35.9 ± 13.7	35.4 ± 15.2	37.8 ± 17.7

Table 2. *Cont.*

Angle (°)	Concentric		Eccentric	
	AST (N.m)		AST (N.m)	
	Preferred	Non-Preferred	Preferred	Non-Preferred
ER10	38.0 ± 14.0	36.0 ± 12.6	39.9 ± 14.7	40.6 ± 17.4
ER0	37.9 ± 13.0	35.9 ± 11.5	43.7 ± 14.2	44.6 ± 16.3
ER-10	38.0 ± 12.0	36.2 ± 11.5	46.5 ± 14.1	47.7 ± 16.4
ER-20	37.9 ± 11.1	36.5 ± 11.1	48.1 ± 13.2	50.8 ± 15.6
ER-30	37.8 ± 10.2	36.6 ± 10.5	50.9 ± 13.0	50.8 ± 14.1
ER-40	37.2 ± 9.6	35.6 ± 9.6	49.8 ± 12.9	48.4 ± 13.9
ER-50	35.8 ± 9.0	32.9 ± 8.4	46.4 ± 13.1	43.1 ± 13.2
ER-60	33.9 ± 9.8	29.2 ± 7.1	39.1 ± 14.3	34.4 ± 12.8
ER-70	29.1 ± 8.1	24.1 ± 6.6	29.2 ± 12.0	23.5 ± 12.7
ER-80	23.0 ± 7.9	17.2 ± 9.1	17.9 ± 10.7	14.5 ± 7.8

Concentric side-to-side IR IPT asymmetry was significantly less than AST at −80° ($p = 0.018$), −70° ($p = 0.045$), −50° ($p = 0.029$), −40° ($p = 0.018$), −30° ($p = 0.016$), −20° ($p = 0.027$), 40° ($p = 0.010$) and 50° ($p = 0.001$). Side-to-side ER IPT asymmetry was significantly less than AST at 50° ($p = 0.011$), 40° ($p = 0.013$) and −80° ($p = 0.00017$) (Figure 1). Eccentric side-to-side IR IPT was significantly less than AST at 50° ($p = 0.000024$) 40° ($p = 0.000063$) 30° ($p = 0.00042$), 20° ($p = 0.006$), 0 ($p = 0.037$), −70° ($p = 0.0013$) and −80° ($p = 0.0034$). Side-to-side ER IPT was significantly less than AST at −80° ($p = 0.00042$), −70° ($p = 0.00026$), −60° ($p = 0.0014$), 30° ($p = 0.0076$), 40° ($p = 0.0032$) and 50° ($p = 0.000016$) (Figure 2). Effect sizes are presented for each significant difference (Figures 1 and 2).

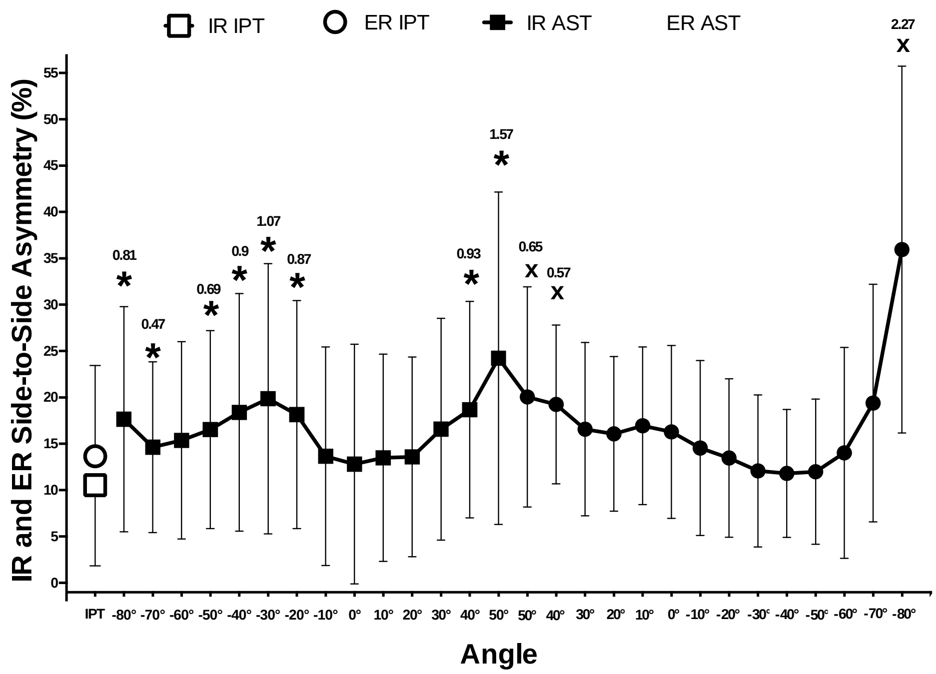

Figure 1. Means ± SD of concentric internal rotators (IR) and external rotators (ER) angle specific torque (AST) and independent peak torque (IPT) side-to-side asymmetry. ***** Significantly less than IR AST; **x** significantly less than ER AST. Effect sizes are presented for each significant difference.

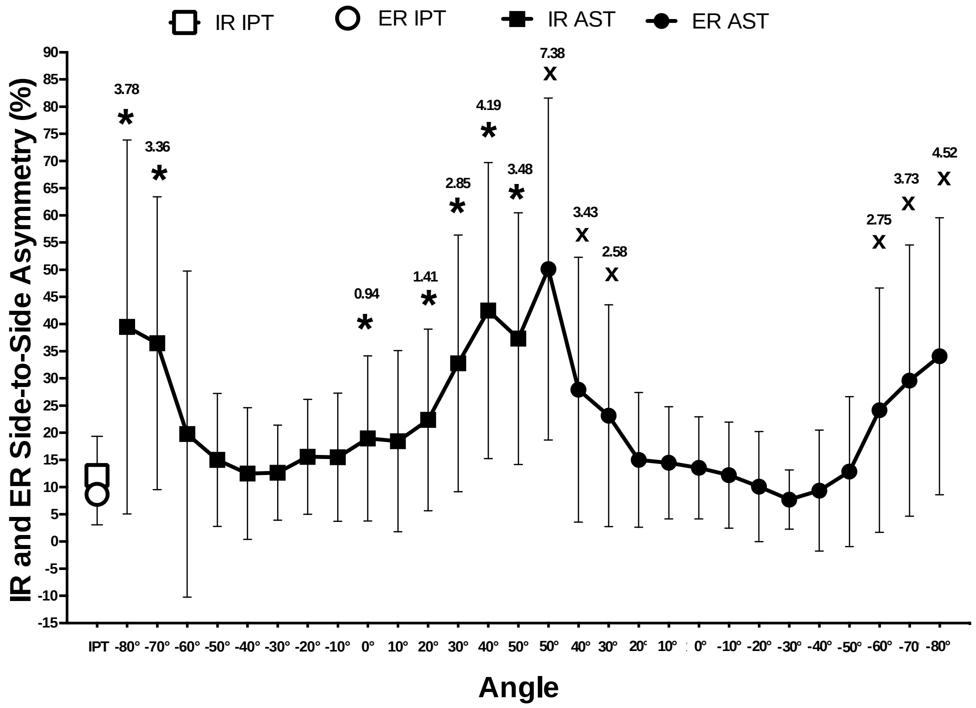

Figure 2. Means ± SD of eccentric internal rotators (IR) and external rotators (ER) angle specific torque (AST) and independent peak torque (IPT) side-to-side asymmetry. ***** Significantly less than IR AST; **x** significantly less than ER AST. Effect sizes are presented for each significant difference.

5. Discussion

The aim of this study was to compare side-to-side asymmetry of the shoulder rotators between IPT and ten-degree AST methods. Our results revealed that concentric IPT was different than AST at eight angles for IR, and three angles for ER. In addition, eccentric IPT was different than AST at seven angles for IR, and six angles for ER. ER differences were found primarily at the beginning and end points of ROM. This demonstrates that IPT might not be an accurate representation of the entire ROM tested in either testing mode. The AST values allow a more precise estimation of strength asymmetry between shoulder rotator muscles. The use of IPT alone may lead to erroneous interpretations of full ROM side-to-side strength differences.

The reliability of IPT and AST for clinical use has been questioned. Brown *et al.* [13] demonstrated a high test-retest reliability of IPT on the Biodex device over a wide velocity spectrum in the knee flexors and extensors. However, Ayala *et al.* [10] showed that this is not transferred to knee unilateral asymmetry calculations, which presented moderate reliability in strength ratios calculated by IPT, and poor reliability in ratios calculated by AST. This was also confirmed for IPT side-to-side calculations of the shoulder rotators in another recent study [14]. This might be explained by strength imbalance calculations being composed of two measurements, where each can vary in two different directions [14].

The IPT is the highest point of the torque curve across a full ROM [15]. This measurement is widely used to indicate maximum strength levels, as well as the occurrence of possible muscle strength imbalance [1,2,5,15–18]. Previous studies have widely utilized IPT as a measure to calculate side-to-side asymmetry of the shoulder internal and external rotators [2,5,14,19–22]. Ellenbecker and Davies [5] concluded that a 5%–10% IPT difference between arms is normal in recreational level upper-limb sport athletes and non-athletes. Our results are slightly outside this range, as both concentric ER and IR IPT, and eccentric IR IPT demonstrated a 10%–15% difference. This may be due to the specific method we used in our isokinetic testing. We measured participants in a supine position with their arms abducted in the frontal plane. This position was based on Forthomme *et al.* [11], which indicated that it results in greater reliability and reproducibility compared to other testing positions. To our knowledge, this position has not been used to determine side-to-side strength imbalance of the shoulder rotators in a non-athletic population. Therefore, direct comparison of our results to established normative values of previous studies [5] is problematic since shoulder asymmetry is probably position dependent as has been shown in other joints [23,24]. Nevertheless, our eccentric ER IPT results were still within the normal range suggested by Ellenbecker and Davies [5].

Our tested velocity may have also played a role in our results. Even though overhead actions such as throwing can reach speeds up to 7200°/s, especially in sports performance [4], we tested at 60°/s in order to avoid a large load range reduction during isokinetic testing, thereby significantly decreasing the total ROM available for analysis [25–27]. Brown *et al.* [26] have shown that very fast isokinetic velocities significantly affect torque patterns. This may also influence side-to-side asymmetry assessment. Greater repetitive use of the preferred arm in throwing actions in recreational and sporting activities may explain our asymmetry results [2,21]. However, previous studies have used a variety of different speeds in order to provide sport specific information about strength imbalance and injury risk in the shoulder rotators [3,4,9]. The use of a single velocity to describe angle specific strength is a limitation of our study.

The limitation of IPT is that it does not take into account the full ROM [15]. This has also been shown to affect the interpretation of shoulder rotators unilateral strength imbalance [1], and many studies have opted to use an AST approach in order to gain more specific information of joint strength imbalances [1,3,4,6–8]. We have previously demonstrated that shoulder IPT dynamic control ratios are significantly different than AST at several angles when calculated by 10° intervals over a 150° total ROM [1]. Similar to this, our present study also found significant differences between side-to-side asymmetry between concentric and eccentric IPT and AST through many ROM angles, especially for IR. In contrast, ER differences were found primarily at the beginning and end of the ROM.

The beginning shoulder ROM (cocking phase) is critical in overhead activities due to full external rotation, and superior and anterior forces being applied to the shoulder; while the end ROM (deceleration phase) requires the arm to be stopped in a short period of time from high velocities [3,4,9]. These points of the ROM have been suggested as where most imbalances may occur, leading to shoulder muscle and ligament injuries [3,4,9]. Previous reports found there were side-to-side asymmetry differences between these phases in athletes [3,4], and college students [9]. This is in agreement with our results and makes the use of AST especially important. In fact we found that eccentric ER AST at 50°, which represents the last deceleration angle at the end of the ROM, had the greatest difference and magnitude of change across all angles when compared to IPT. While ER strength is important for the preparation and deceleration phases of overhead actions, IR strength is primarily used for the acceleration phase in overhead throwing and racket sports [2,4]. A strength balance of IR and ER between upper limbs across the entire ROM, especially at the beginning and end [3–5,9], may not only help to avoid and rehabilitate injuries, but help determine performance in overhead sports [21]. Although unilateral overhead sports may result in dissimilar side-to-side differences, clinicians have assumed that peak torque value equivalency between shoulders may be used as a target for prevention and rehabilitation of injury in athletes and physically active individuals [5,21]. A strength balance between the upper limbs could be used to precisely identify where primary imbalances are present and prescribe strength exercises to diminish these differences at the affected angles. However, the greatest side-to-side asymmetry differences we found were near the extreme ranges and could be due to muscle sarcomeres being at a disadvantage on the length-tension curve and thereby generating low torques [28].

We also found that although IPT occurred at similar angles for concentric strength, they were at non-corresponding angles for eccentric strength. This could influence decision making of clinicians and physical therapists when interpreting shoulder strength results. Our results demonstrate that AST may provide a more accurate and detailed assessment of side-to-side asymmetry across the full ROM. This information can be used for the prescription of strength training programs based on bilateral equivalency for optimal performance and prevention of injury caused by repetitive sporting activities [20,21].

6. Conclusions

This study demonstrates that IPT is significantly less than AST at several angles when measuring side-to-side asymmetry of the shoulder rotators. IPT represents only one single angle across the entire ROM tested, and may occur at non-corresponding angles for eccentric strength. Therefore, AST is suggested as a new approach, which allows for measurement of the specific angles where strength differences between arms are present. This information could be used to assist in the prescription of strength training programs that focus on the precise angles where asymmetry occurs to enhance performance and reduce risk of shoulder injuries.

Author Contributions

Cassio V. Ruas, Ronei S. Pinto and Lee E. Brown were involved in study design and data interpretation. Cassio V. Ruas and Lee E. Brown were involved in data collection. Cassio V. Ruas, Ronei S. Pinto, Eduardo L. Cadore and Lee E. Brown were involved in manuscript writing and revision.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Ruas, C.V.; Pinto, R.S.; Hafenstine, R.W.; Pereira, M.C.; Brown, L.E. Specific joint angle assessment of the shoulder rotators. *Isokinet. Exerc. Sci.* **2014**, *22*, 197–204.
2. Gulick, D.T.; Dustman, C.S.; Ossowski, L.L.; Outslay, M.D.; Thomas, C.P.; Trucano, S. Side dominance does not affect dynamic control strength ratios in the shoulder. *Isokinet. Exerc. Sci.* **2001**, *9*, 79–84.
3. Ng, G.Y.; Lam, P.C. A study of antagonist/agonist isokinetic work ratios of shoulder rotators in men who play badminton. *J. Orthop. Sports Phys. Ther.* **2002**, *32*, 399–404.

4. Yildiz, Y.; Aydin, T.; Sekir, U.; Kiralp, M.Z.; Hazneci, B.; Kalyon, T.A. Shoulder terminal range eccentric antagonist/concentric agonist strength ratios in overhead athletes. *Scand. J. Med. Sci. Sports* **2006**, *16*, 174–180.
5. Ellenbecker, T.S.; Davies, G.J. The application of isokinetics in testing and rehabilitation of the shoulder complex. *J. Athl. Train.* **2000**, *35*, 338–350.
6. Kellis, E.; Katis, A. Quantification of functional knee flexor to extensor moment ratio using isokinetics and electromyography. *J. Athl. Train.* **2007**, *42*, 477–485.
7. Dehail, P.; Gagnon, D.; Noreau, L.; Nadeau, S. Assessment of agonist-antagonist shoulder torque ratios in individuals with paraplegia: A new interpretative approach. *Spinal Cord.* **2008**, *46*, 552–558.
8. Evangelidis, P.E.; Pain, M.T.; Folland, J. Angle-specific hamstring-to-quadriceps ratio: A comparison of football players and recreationally active males. *J. Sports Sci.* **2015**, *33*, 309–319.
9. Scoville, C.R.; Arciero, R.A.; Taylor, D.C.; Stoneman, P.D. End range eccentric antagonist/concentric agonist strength ratios: A new perspective in shoulder strength assessment. *J. Orthop. Sports Phys. Ther.* **1997**, *25*, 203–207.
10. Ayala, F.; De Ste Croix, M.; Sainz de Baranda, P.; Santonja, F. Absolute reliability of hamstring to quadriceps strength imbalance ratios calculated using peak torque, joint angle-specific torque and joint rom-specific torque values. *Int. J. Sports Med.* **2012**, *33*, 909–916.
11. Forthomme, B.; Dvir, Z.; Crielaard, J.M.; Croisier, J.L. Isokinetic assessment of the shoulder rotators: A study of optimal test position. *Clin. Physiol. Funct. Imaging* **2011**, *31*, 227–232.
12. Rhea, M.R. Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J. Strength Cond. Res.* **2004**, *18*, 918–920.
13. Brown, L.E.; Whitehurst, M.; Bryant, J.R.; Buchalter, D.N. Reliability of the biodex system 2 isokinetic dynamometer concentric mode. *Isokinet. Exerc. Sci.* **1993**, *3*, 160–163.
14. Edouard, P.; Codine, P.; Samozino, P.; Bernard, P.L.; Herisson, C.; Gremeaux, V. Reliability of shoulder rotators isokinetic strength imbalance measured using the biodex dynamometer. *J. Sci. Med. Sport* **2013**, *16*, 162–165.
15. Brown, L.E.; Weir, J.P. Asep procedures recommendation i: Accurate assessment of muscular strength and power. *J. Exerc. Physiol. Online* **2001**, *4*, 1–21.
16. Ruas, C.V.; Minozzo, F.; Pinto, M.D.; Brown, L.E.; Pinto, R.S. Lower-extremity strength ratios of professional soccer players according to field position. *J. Strength Cond. Res.* **2015**, *29*, 1220–1226.
17. Ruas, C.V.; Pinto, M.D.; Brown, L.; Minozzo, F.; Mil-Homens, P.; Pinto, R.S. The association between conventional and dynamic control knee strength ratios in elite soccer players. *Isokinet. Exerc. Sci.* **2015**, *23*, 1–12.
18. Brown, L.E.; Sjostrom, T.; Comeau, M.J.; Whitehurst, M.; Greenwood, M.; Findley, B.W. Kinematics of biophysically asymmetric limbs within rate of velocity development. *J. Strength Cond. Res.* **2005**, *19*, 298–301.
19. Hurd, W.J.; Kaplan, K.M.; ElAttrache, N.S.; Jobe, F.W.; Morrey, B.F.; Kaufman, K.R. A profile of glenohumeral internal and external rotation motion in the uninjured high school baseball pitcher, part ii: Strength. *J. Athl. Train.* **2011**, *46*, 289–295.

20. Codine, P.; Bernard, P.L.; Pocholle, M.; Benaim, C.; Brun, V. Influence of sports discipline on shoulder rotator cuff balance. *Med. Sci. Sports Exerc.* **1997**, *29*, 1400–1405.
21. Perrin, D.H.; Robertson, R.J.; Ray, R.L. Bilateral lsokinetic peak torque, torque acceleration energy, power, and work relationships in athletes and nonathletes. *J. Orthop. Sports Phys. Ther.* **1987**, *9*, 184–189.
22. Sirota, S.C.; Malanga, G.A.; Eischen, J.J.; Laskowski, E.R. An eccentric- and concentric-strength profile of shoulder external and internal rotator muscles in professional baseball pitchers. *Am. J. Sports Med.* **1997**, *25*, 59–64.
23. Findley, B.W.; Brown, L.E.; Whitehurst, M.; Keating, T.; Murray, D.P.; Gardner, L.M. The influence of body position on load range during isokinetic knee extension/flexion. *J. Sport Sci. Med.* **2006**, *5*, 400–406.
24. Findley, B.W.; Brown, L.E.; Whitehurst, M.; Gilbert, R.; Groo, D.R.; O'neal, J. Sitting *vs.* Standing isokinetic trunk extension and flexion performance differences. *J. Strength Cond Res.* **2000**, *14*, 310–315.
25. Brown, L.E.; Whitehurst, M.; Gilbert, R.; Buchalter, D.N. The effect of velocity and gender on load range during knee extension and flexion exercise on an isokinetic device. *J. Orthop. Sports Phys. Ther.* **1995**, *21*, 107–112.
26. Brown, L.E.; Whitehurst, M.; Findley, B.W.; Gilbert, R.; Buchalter, D.N. Isokinetic load range during shoulder rotation exercise in elite male junior tennis players. *J. Strength Cond. Res.* **1995**, *9*, 160–164.
27. Brown, L.E.; Whitehurst, M.; Findley, B.W.; Gilbert, R.; Groo, D.R.; Jimenez, J.A. Effect of repetitions and gender on acceleration range of motion during knee extension on an isokinetic device. *J. Strength Cond. Res.* **1998**, *12*, 222–225.
28. Huxley, A.F.; Niedergerke, R. Structural changes in muscle during contraction. *Nature* **1954**, *173*, 971–973.