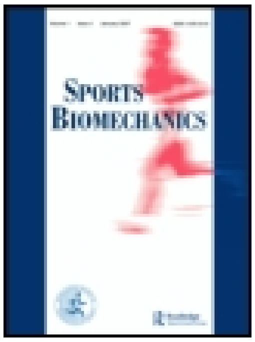

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Functional shoulder ratios with high velocities of shoulder internal rotation are most sensitive to determine shoulder rotation torque imbalance: a cross-sectional study with elite handball players and controls

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ABSTRACT

The aim of the present study was to determine which approach to calculating shoulder ratios is the most sensitive for determining shoulder torque imbalance in handball players. Twenty-six participants (handball athletes, $n = 13$; healthy controls, $n = 13$) performed isokinetic concentric and eccentric shoulder internal rotation (IR) and external rotation (ER) assessment at 60, 180 and 300°/s. We used eight approaches to calculating shoulder ratios: four concentric (i.e. concentric ER torque divided by concentric IR torque), and four functional (i.e. eccentric ER torque divided by concentric IR torque) at the velocities of 60, 180 and 300°/s for both IR and ER, and combining 60°/s of ER and 300°/s of IR. A three factorial ANOVA (factors: shoulder ratios, upper limb sides, and groups) along with Tukey's post-hoc analysis, and effect sizes were calculated. The findings suggested the functional shoulder ratio combining 60°/s of ER and 300°/s of IR is the most sensitive to detect differences between upper limbs for handball players, and between players and controls for the dominant side. The functional shoulder ratio combining 60°/s of ER with 300°/s of IR seems to present advantages over the other approaches for identifying upper limb asymmetries and differences in shoulder torque balance related to throwing.

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Biomechanics; evaluation; isokinetic; muscle imbalance; shoulder injuries

Introduction

Shoulder injuries are a common musculoskeletal problem in sports that require overarm throwing, as for example, handball (Edouard et al., 2013; Langevoort, Myklebust, Dvorak, & Junge, 2007). The incidence of time-loss injury has been estimated to range from 11.2 to 14.3

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per 1,000 exposure hours in handball matches (Laver & Myklebust, 2015). The incidence of acute or chronic shoulder pain in handball players has been reported to range between 30 and 57% (König, Bbrtram, & Klöttschen, 1995; Laver & Myklebust, 2015; Myklebust, Hasslan, Bahr, & Steffen, 2013). Seil, Rupp, Tempelhof, and Kohn (1998) found chronic shoulder pain to be the most frequent symptom among handball players. Based on data from elite-level international competitions, 16.7% of all handball injuries occurred in the shoulder joint (Laver & Myklebust, 2015).

Repetitive overarm throwing may contribute to the high incidence of chronic shoulder pain in handball players (Langevoort, 1996). It has been estimated that handball players make approximately 48,000 throws in a season (Langevoort, 1996). In overarm throwing, shoulder internal rotation movement plays an important role in accelerating the upper extremity, leading to high-speed movement prior to ball release (Debanne & Laffaye, 2011; van den Tillaar & Ettema, 2007). The eccentric action of external rotator muscles is crucial to decelerate such movements as well as maintain the stability of the glenohumeral joint (David et al., 2000; Rokito, Jobe, Pink, Perry, & Brault, 1998).

Imbalance between shoulder internal and external rotator muscles strength has been considered as a contributing factor for shoulder injury (Cook, Gray, Savinar-Nogue, & Medeiros, 1987; Edouard et al., 2013; Ellenbecker & Mattalino, 1997; Stickley, Hetzler, & Freemyer, 2008; Wang, Macfarlane, & Cochrane, 2000). In a prospective study, handball players with imbalanced shoulder muscle strength showed an increased risk for shoulder injury by 2.57 times (Edouard et al., 2013).

Due to adaptations following repetitive throwing, handball players tend to develop stronger shoulder internal rotator muscles, in comparison to the external rotator muscles, in their dominant upper limbs (Ellenbecker & Mattalino, 1997; Noffal, 2003; Zanca, Oliveira, Saccol, Ejnisman, & Mattiello-Rosa, 2011). The imbalance between internal and external rotator is unlikely to be present on the non-dominant side (Ellenbecker & Mattalino, 1997; Wang et al., 2000). The balance between internal and external rotator muscles is expected to differ between players' dominant and non-dominant upper limbs (Ellenbecker & Mattalino, 1997; Ellenbecker & Roetert, 2003; Wang et al., 2000). Such between-sides differences might provide information on shoulder muscle imbalance related to the practice of handball (Edouard et al., 2013; Noffal, 2003).

Shoulder rotation torque ratio has been proposed to objectively indicate the dynamic balance and risk of injury in the glenohumeral joint (Andrade, Fleury, de Lira, Dubas, & da Silva, 2010; Ellenbecker & Mattalino, 1997; Ellenbecker & Roetert, 2003; Noffal, 2003; Zanca, Oliveira, Saccol, Ejnisman, et al., 2011). The ratio between concentric external and concentric internal rotation torque (i.e. concentric shoulder ratio) was initially proposed as an approach for assessing the dynamic balance and risk of injury in the joint (Ivey, Calhoun, Rusche, & Bierschenk, 1985). However, such ratio does not reflect the physical demands imposed to shoulder rotator muscles. The ratio between eccentric external and concentric internal rotation torque (i.e. functional shoulder ratio) has been suggested to be a superior approach (Scoville, Arciero, Taylor, & Stoneman, 1997; Wilk, Andrews, Arrigo, Keirns, & Erber, 1993). The advantage of the functional shoulder ratio is that it accounts for the balance between concentric torque performed by shoulder internal rotators to accelerate the arm as well as eccentric torque performed by the shoulder's external rotator muscles to decelerate the arm (David et al., 2000; Rokito et al., 1998).

The capacity to generate muscle torque is influenced by the velocity at which a movement occurs (Davies & Ellenbecker, 2012). The physiological force–velocity relationship describes well how muscle peak torque changes as a consequence of velocity during concentric actions. The higher the velocity is, the lower the muscle peak torque (Beam & Adams, 2014). However, for eccentric muscle contraction, the force–velocity relationship does not follow the classical description (Andrade et al., 2010; Beam & Adams, 2014). For example, female handball players showed lower muscle strength in their concentric shoulder internal and external rotations while performing fast compared to slow movements during isokinetic assessments (Andrade et al., 2010). However, during eccentric actions, players presented lower peak torque magnitude during slow compared to fast movements (e.g. 60 vs. 300°/s) (Andrade et al., 2010).

Assessment of shoulder muscle imbalance is influenced by the type of action (i.e. concentric and eccentric) and velocity in which such movement is performed (Davies & Ellenbecker, 2012). Identifying the best combination between type of action and movement velocity of shoulder internal and external rotations might be helpful to implement protocols for prevention and rehabilitation of shoulder injuries. Currently, it remains unclear which isokinetic velocity and type of muscle action should be used to better assess and identify shoulder internal and external rotation muscle imbalances.

The aim of the present study was to explore several approaches to calculate shoulder rotation torque balance, and to determine which of these approaches is the most sensitive to identify shoulder torque muscle imbalance. We hypothesised that functional shoulder ratios at high velocity of internal rotation would be the best approaches to detect differences in shoulder ratio between upper limbs (dominant vs. non-dominant upper limb) and between a group of handball elite athletes and healthy controls not involved in sports with asymmetrical movements. We also expected the athletes to present: (i) lower shoulder ratios at their dominant compared to their non-dominant upper limbs; and (ii) lower shoulder ratios at their dominant side compared to controls.

Method

This cross-sectional study involved repeated measures of shoulder internal and external rotation torque at different testing velocities. It was approved by the Porto Biomechanics Laboratory (LABIOMEP) ethics board (Project number: cet-042013), and all participants signed an informed written consent form, as per the Declaration of Helsinki.

Thirteen male elite professional handball players, all five-time winners of the Portuguese premier professional handball league, were enrolled in the study (Table 1). Aiming to recruit elite handball players, the coach of the handball team with the best performance in the previous years was contacted by the research team and the purpose of the study was explained. The players most involved in offensive tasks (i.e. circle runners and wingers) were selected

Table 1. Anthropometrics (mean ± SD) and independent sample *t*-test data.

	Handball players ($N = 13$)	Control group ($N = 13$)	*t*-test
Age (years)	23.4 ± 4.1	27.4 ± 5.2	$t(24) = -1.967, p = 0.061$
Weight (kg)	89.8 ± 6.6	78.4 ± 10.9	$t(24) = 3.239, p = 0.003$
Height (m)	1.9 ± 0.1	1.8 ± 0.1	$t(24) = 4.070, p < 0.001$
BMI (kg/m^2)	24.7 ± 1.0	24.1 ± 2.8	$t(24) = 0.685, p = 0.506$

by the coach and invited to participate in this study. None of the players presented musculoskeletal symptoms at the time of assessment or suffered shoulder injury in the previous year. Another 13 male participants were recruited, by convenience, from the university staff to form the control group (Table 1). Participants from the control group were excluded if they presented any musculoskeletal symptoms in the upper limbs or trunk, had suffered shoulder injury in the previous year, or currently practised any asymmetrical sport (e.g. handball, tennis, fencing, throwing). No significant differences in age and body mass index were found between groups, although handball players had greater height and body weight than the controls (Table 1). To minimise the influence of these differences in body weight between groups, data were normalised to participants' body weight.

The Biodex Multi-Joint System 4 Pro (Biodex Medical System Inc., Shirley, NY, USA) was used to assess concentric and eccentric shoulder internal and external rotation torques, with a frequency set at 100 Hz. Both dominant and non-dominant sides were assessed at 60, 180 and 300°/s, and the dominant side was defined as the throwing arm. Participants were evaluated while sitting, with 90° shoulder abduction (i.e. on the frontal plane) and elbow flexion (Andrade et al., 2010; Zanca, Oliveira, Saccol, & Mattiello-Rosa, 2011), which most readily simulated a throwing position. This position showed good-to-excellent between-days reliability for peak torque values (Hellwig & Perrin, 1991). Participant positioning and isokinetic testing followed the manufacturer's specifications for positioning, stabilisation and gravity correction. The olecranon of the ulna was aligned with the dynamometer axis of rotation, and internal and external rotation torques were measured through a range of motion of 120°, ranging from 90° shoulder external rotation to 30° shoulder internal rotation.

Prior to data collection, handball players warmed up as they would prior to normal training, and controls performed the same exercises, which included 2 series of 10 active movements of shoulder elevation, adduction–abduction and circumduction. Participants next familiarised themselves with the testing procedures by performing three submaximal repetitions at each test velocity in each mode (i.e. shoulder internal and external concentric and eccentric rotations). Ultimately, participants performed a total of 12 trials of 5 reciprocal (i.e. concentric–concentric or eccentric–eccentric) maximal effort repetitions, which consisted of a combination of 3 velocities (i.e. 60, 180, and 300°/s), 2 types of muscle actions (i.e. concentric and eccentric), and 2 types of upper limbs (i.e. dominant and non-dominant). An interval of 3 min between trials was adopted to minimise the risk of fatigue. The side of test (dominant and non-dominant upper limbs) was changed between each two trials. The order of test velocities and the upper limb were randomised. Participants performed a test in a specific velocity with one upper limb at a time, and then performed the testing with the next velocity (as per random allocation). For example, when trials with the first randomly selected velocity began with the dominant side, the testing was followed by testing the non-dominant side. Participants received verbal encouragement to perform the tasks with maximum effort.

Data (i.e. torque, velocity, and angle) were exported to MATLAB 7.12 (MathWorks Inc., Natick, MA, USA), and a custom-made code was written to detect peak torque at each repetition. As research has shown, the range of movement within which participants can sustain a constant velocity (i.e. isokinetic load range) (Brown, 2000; Brown, Whitehurst, Findley, Gilbert, & Buchalter, 1995a; Brown, Whitehurst, Gilbert, & Buchalter, 1995b) can differ according to different isokinetic velocities. It is also well-known that at the extreme ranges of motion (i.e. beginning and end), there is noise in torque data, since the velocity at these ranges (i.e. the artefact region) is inconstant (Brown, 2000; Brown et al., 1995a). Therefore, to avoid analysing data at ranges within which velocity was not constant, only the isokinetic load range was considered. All waveforms were visually inspected to assure that peak values were not located within artefact regions, and the average peak torque of the five repetitions was calculated and normalised by body weight. After all participants successfully performed all exercises for assessment, eight shoulder ratio approaches were calculated (Table 2).

All ratios—also referred to as approaches—used in this study are commonly employed when assessing torque ratios (Ellenbecker & Davies, 2000). Two approaches combining different testing velocities (i.e. concentric and functional shoulder ratio combining low external rotation and high internal rotation velocity) were also included. Eccentric actions at high velocities can be uncomfortable and require more complex coordination, and that may impact on participants performing maximal torque. Shoulder ratios combining low external rotation and high internal rotation velocities allow participants to perform eccentric action at a comfortable test velocity. On the other hand, assessing internal rotation torque at a higher velocity better simulates athletic movement (Davies & Ellenbecker, 2012).

Approaches combining velocities have previously been used to assess knee torque balance (Iga, George, Lees, & Reilly, 2009). A total of eight approaches for assessing shoulder torque muscle imbalance were assessed. Based on studies assessing overhead throwers (Ellenbecker & Mattalino, 1997; Noffal, 2003; Zanca, Oliveira, Saccol, Ejnisman, et al., 2011), low shoulder ratio magnitudes may be interpreted as larger shoulder internal rotator muscles strength compared to shoulder external rotator muscles strength.

Statistical analysis was performed using Statistica® v.8 (Statsoft®, Tulsa, OK, USA) with α set at 0.05. Independent sample *t*-tests were used to compare anthropometric data between groups, and an 8 × 2 × 2 mixed-model analysis of variance (ANOVA) was calculated for participants' shoulder ratios. Three factors were used when calculating ANOVA: the eight approaches used for calculating shoulder ratios, the upper limb side (i.e. dominant and non-dominant) and group (i.e. handball players' group and control group). The approaches and upper limb side were considered as within-participant factors, while the group was considered as between-participant factor. If interactions between factors were found, post-hoc

Table 2. Description of the eight shoulder rotation torque ratios.

Shoulder ratios	Description of calculation
(1) Concentric ratio 60°/s	Concentric shoulder external rotation peak torque at 60°/s divided by concentric shoulder internal rotation peak torque at 60°/s
(2. Functional ratio 60°/s	Eccentric shoulder external rotation peak torque at 60°/s divided by concentric shoulder internal rotation peak torque at 60°/s
(3) Concentric ratio 180°/s	Concentric shoulder external rotation peak torque at 180°/s divided by concentric shoulder internal rotation peak torque at 180°/s
(4) Functional ratio 180°/s	Eccentric shoulder external rotation peak torque at 180°/s divided by concentric shoulder internal rotation peak torque at 180°/s
(5) Concentric ratio 300°/s	Concentric shoulder external rotation peak torque at 300°/s divided by concentric shoulder internal rotation peak torque at 300°/s
(6) Functional ratio 300°/s	Eccentric shoulder external rotation peak torque at 300°/s divided by concentric shoulder internal rotation peak torque at 300°/s
(7) Concentric ratio 60:300°/s	Concentric shoulder external rotation peak torque at 60°/s divided by concentric shoulder internal rotation peak torque at 300°/s
(8) Functional ratio 60:300°/s	Eccentric shoulder external rotation peak torque at 60°/s divided by concentric shoulder internal rotation peak torque at 300°/s

analysis using the Tukey's honest significant difference was calculated. Post-hoc analysis was performed for the highest order of interaction between factors. The ANOVA assumptions were met: data presented normal distribution, as indicated by the Shapiro–Wilk test ($p > 0.05$); sphericity criteria were met, as verified by Mauchly's test. The partial Eta square (η^2) was used to measure the effect sizes of ANOVA interactions. A η^2 of 0.01 or less was considered as small, while η^2 of 0.06 was middling, and η^2 of 0.14 or more was considered as large.(Stevens, 2009) The Cohen's *d* was calculated as a measure of effect size for between-group and between-upper limb comparisons (Cohen, 1988). Cohen's *d* lower than 0.2 was considered irrelevant, between 0.2 and 0.49 was small, between 0.50 and 0.8 was medium, and greater than 0.8 was considered high (Cohen, 1988).

The within-trial reliability for peak torque measurements (shoulder internal and external rotation at 60, 180, and 300°/s) was calculated using the intraclass correlation coefficient (two-way mixed model, absolute agreement definition, ICC [3,1]) for both groups. The five repetitions of shoulder rotation were used as input in the model. Reliability analysis was performed using SPSS (version 22, IBM Corporation, Chicago, IL, USA).

Results

Excellent within-trial reliability was found for all conditions. All torque ICC values were greater than 0.917.

We found statistically significant interactions with a medium effect size ($F(7, 168) = 2.533$, $p = 0.016$, $\eta^2 = 0.095$) between the three factors (approaches, upper limbs and groups). Descriptive statistics and information of between-group and between-upper limb comparisons are presented in Figure 1 and Table 3.

Post-hoc analyses showed no between-group or between-upper limb statistically significant differences when using five of the eight approaches (i.e. concentric ratio 60°/s, concentric ratio 180°/s, concentric ratio 300°/s, functional ratio 60°/s and functional ratio 180°/s). When the concentric ratio 60:300°/s was used, both handball players and controls showed smaller shoulder ratios with high effect sizes (Table 4) in their dominant than their non-dominant upper limbs, and similar values were found between handball players and controls in both upper limbs (Figure 1 and Table 3). The functional ratio 300°/s, and the functional ratio 60:300°/s showed similar patterns. Handball players showed lower ratio values compared to the control group for the dominant side. In the non-dominant upper limb, values between groups were similar. Furthermore, the dominant side of the handball players depicted lower values of shoulder ratio compared to the non-dominant side. High effect sizes were observed in all statistically significant differences (Table 4). Similar shoulder ratios between upper limbs were observed in the control group (Figure 1).

Discussion and implications

In this study, we assessed shoulder torque ratios in both upper limbs of elite handball athletes and controls not involved in sports with asymmetrical movements. We found that shoulder ratios at high velocity of internal rotation (i.e. functional ratio 300°/s and functional ratio 60:300°/s) were the best approaches to detect differences in shoulder ratio between upper limbs (dominant vs. non-dominant upper limb) and between groups (handball players vs. control group). Based on that, our first hypothesis was accepted. The functional ratio 300°/s

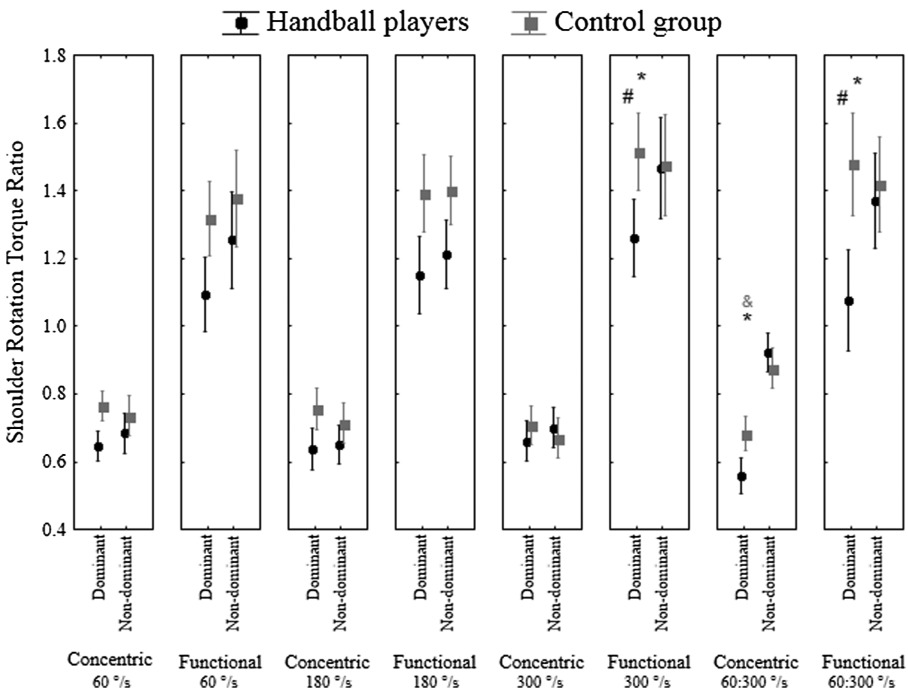

Figure 1. Shoulder rotation torque ratios.
Notes: Black circles represent handball players, and grey squares represent control group. Vertical bars denote 95% confidence interval. #, Statistical significant differences between handball players and control group. *, Statistical significant differences between handball players' dominant and non-dominant upper limbs. &, Statistical significant differences between control participants' dominant and non-dominant upper limbs.

Table 3. Mean, SD and range of the shoulder rotation torque ratios for the control and handball players.

	Dominant limb		Non-dominant limb	
Shoulder ratios	Mean ± SD	(Range)	Mean ± SD	(Range)
Control group				
Concentric ratio 60°/s	0.77 ± 0.10	(0.57; 0.92)	0.74 ± 0.11	(0.58; 0.94)
Functional ratio 60°/s	1.32 ± 0.19	(1.08; 1.75)	1.38 ± 0.22	(0.97; 1.77)
Concentric ratio 180°/s	0.76 ± 0.13	(0.57; 1.03)	0.71 ± 0.10	(0.56;0.90)
Functional ratio 180°/s	1.39 ± 0.22	(1.03; 1.83)	1.40 ± 0.22	(1.14; 1.81)
Concentric ratio 300°/s	0.71 ± 0.11	(0.58; 0.95)	0.67 ± 0.12	(0.53; 0.86)
Functional ratio 300°/s	1.52 ± 0.17	(1.32; 1.86	1.48 ± 0.24	(1.15; 2.10)
Concentric ratio 60:300°/s	0.68 ± 0.12	(0.51; 0.84)	0.88 ± 0.12	(0.74; 1.13)
Functional ratio 60:300°/s	1.48 ± 0.33	(1.15; 2.32)	1.42 ± 0.27	(1.10; 2.06)
Handball players				
Concentric ratio 60°/s	0.65 ± 0.04	(0.57; 0.71)	0.68 ± 0.10	(0.50; 0.82)
Functional ratio 60°/s	1.09 ± 0.19	(0.82; 1.35)	1.26 ± 0.27	(0.71; 1.81)
Concentric ratio 180°/s	0.64 ± 0.08	(0.49; 0.78)	0.65 ± 0.11	(0.49; 0.89)
Functional ratio 180°/s	1.15 ± 0.17	(0.77; 1.45)	1.21 ± 0.12	(0.97; 1.37)
Concentric ratio 300°/s	0.66 ± 0.09	(0.55; 0.86)	0.70 ± 0.09	(0.58; 0.85)
Functional ratio 300°/s	1.26 ± 0.23	(0.86; 1.63)	1.47 ± 0.28	(1.05; 1.91)
Concentric ratio 60:300°/s	0.56 ± 0.05	(0.50; 0.67)	0.92 ± 0.07	(0.80; 1.03)
Functional ratio 60:300°/s	1.08 ± 0.18	(0.81; 1.35)	1.37 ± 0.22	(0.87; 1.73)

and functional ratio 60:300°/s were the approaches that detected statistically significant

Table 4. Effect sizes for statistical significant differences from post-hoc analysis.

Approach	Comparison	Cohen's *d*
Functional ratio 300°/s	Between-groups (dominant)	0.82
	Upper-limb sides (handball)	1.30
Concentric ratio 60:300°/s	Upper-limb sides (control)	5.72
	Upper-limb sides (handball)	1.61
Functional ratio 60:300°/s	Between-groups (dominant)	1.48
	Upper-limb sides (handball)	1.59

differences with the largest effect sizes when comparing (i) dominant and non-dominant upper limbs in handball players, and (ii) handball players and controls when assessing the dominant side. Based on these findings, our second hypothesis was also accepted.

Three approaches suggested differences in torque ratio (functional ratio 300°/s, concentric ratio 60:300°/s and functional ratio 60:300°/s), while the other five did not identify any differences in torque ratio when comparing dominant versus non-dominant upper limbs, and groups (athletes vs. control). The concentric ratio 60:300°/s suggested differences between upper limb sides in the control group. Thus, it seems that the functional ratio 300°/s and the functional ratio 60:300°/s are the most sensitive for identifying the neuromuscular adaptations related to throwing.

For the present study, we assumed that our sample of handball players presented shoulder imbalance in their dominant upper limbs and the control group presented shoulder strength symmetry between their upper limbs. Such assumptions are supported by the literature (Andrade et al., 2010; Noffal, 2003; Zanca, Oliveira, Saccol, Ejnisman, et al., 2011). Previous studies reported lower values for the functional shoulder ratio with high velocity in throwers than in control participants (Noffal, 2003; Zanca, Oliveira, Saccol, Ejnisman, et al., 2011), and similar shoulder ratios in the non-dominant upper limb between throwers and non-throwers (Noffal, 2003). Thus, we believe the experimental design of the present study allows to infer on the most sensitive approach to determine imbalance between shoulder rotator muscles. Together, these findings suggest that functional approaches at high velocity (i.e. functional ratio 300°/s) and combining velocities approaches (functional ratio 60:300°/s) should be used for assessing shoulder muscle imbalances in throwers.

It is well documented in the literature that athletes involved with asymmetrical upper limb tasks (e.g. handball) present higher shoulder internal rotation torque on the dominant limb (Ellenbecker & Mattalino, 1997; Noffal, 2003; Zanca, Oliveira, Saccol, Ejnisman, et al., 2011). Such torque gains are believed to stem from an emphasis on explosive activities, such as throwing, and resistance training of muscles primary involved in increasing ball speed during throwing (i.e. the pectoral major and latissimus dorsi). As such, shoulder ratios in the dominant limbs are expected to be lower than in their non-dominant upper limbs in handball athletes. However, only functional approaches with shoulder internal rotation at 300°/s reflected those specific adaptations. The use of high velocities of shoulder internal rotation might reflect better the throwing movement compared to slow velocities (Ellenbecker & Davies, 2000). Using high velocity for shoulder internal rotation seems to be a better marker for adaptations caused by a sport where high velocity overhead throwing is crucial for performance. The changes in shoulder ratios observed in the dominant limb of handball players could suggest an imbalance that might lead to rotator cuff fatigue sooner with volume overuse. Such fatigue might promote further increases in changes in the shoulder ratios, increasing the risk of shoulder injuries. For those not involved in sports with asymmetrical demand in the upper limbs (e.g. participants in our control group) such changes in shoulder ratios were not observed.

The present study was not designed to verify whether changes in shoulder torque rotation are an associated factor or risk factor for shoulder injury. Thus, it is unclear whether or not the shoulder muscle imbalances observed by the functional ratio 300°/s and functional ratio 60:300°/s might be a contributing factor for future shoulder injury. However, imbalance between shoulder internal and external rotator muscles has been shown to be a factor underlying shoulder dysfunction in throwers (Cook et al., 1987; Edouard et al., 2013; Ellenbecker & Mattalino, 1997; Stickley et al., 2008; Wang et al., 2000). It is plausible to consider the shoulder ratios identified in the present study as the most sensitive to determine shoulder torque imbalances. Thus, our findings support the use of the functional ratio 300°/s and functional ratio 60:300°/s in future studies aiming to explore shoulder rotation torque imbalance in the contexts of prevention and rehabilitation of shoulder injuries.

The method used to assess shoulder muscle torque imbalance affects shoulder ratio results. When female handball players were evaluated, similar shoulder ratios between upper limbs were found for concentric ratios (60, 180 and 300°/s), and functional ratio 180°/s (Andrade et al., 2010). The only statistically significant difference emerged with the functional ratio 300°/s, for which lower values in the dominant upper limb were found (Andrade et al., 2010). Those findings concur with results observed in the present study, albeit in terms of male handball players. In this study, we also examined shoulder ratios combining low velocities of external rotation with high velocities of internal rotation. These combined ratios (i.e. concentric ratio 60:300°/s and functional ratio 60:300°/s) were also able to detect differences between handball players' upper limbs.

Overall, both functional shoulder ratios at high velocity (functional ratio 300°/s and functional ratio 60:300°/s) detected changes in shoulder torque balance related to throwing. Two factors support the use of the functional ratio 60:300°/s over the functional ratio 300°/s to assess shoulder imbalance. First, the functional ratio 60:300°/s showed greater effect sizes than the functional ratio 300°/s: between-limb comparisons (functional ratio 60:300°/s, Cohen's $d = 1.48$; functional ratio 300°/s, Cohen's $d = 1.30$); and between-groups comparisons (functional ratio 60:300°/s, Cohen's $d = 1.59$; functional ratio 300°/s, Cohen's $d = 0.81$). Second, assessing isokinetic eccentric external rotation actions with low velocities is less demanding to and more comfortable for participants than faster velocities.

In this study, we calculated shoulder torque ratios using the peak torque of shoulder internal and external rotator muscles. However, that method does not evaluate shoulder muscle imbalance during the entire shoulder range of motion. That approach has been proposed as a way of obtaining an overall index of shoulder performance (Andrade et al., 2010; Ellenbecker & Mattalino, 1997; Ellenbecker & Roetert, 2003; Noffal, 2003; Zanca, Oliveira, Saccol, Ejnisman, et al., 2011). Recently, another way of processing the data (i.e. the angle-specific torque) has been proposed to analyse shoulder muscle imbalance (Ruas, Pinto, Cadore, & Brown, 2015; Ruas, Pinto, Hafenstine, Pereira, & Brown, 2014). That method calculates shoulder ratios for every 10° of the range of motion and thus allows to identify specific ranges of movement where shoulder imbalance may be present (Ruas et al., 2014). Though the new method seems promising, no studies have confirmed that it presents advantages for preventing shoulder injuries or improving throwing performance compared to the traditional approach to calculating shoulder muscle ratio (Andrade et al., 2010; Ellenbecker & Mattalino, 1997; Ellenbecker & Roetert, 2003; Noffal, 2003; Zanca, Oliveira, Saccol, Ejnisman, et al., 2011).

The present study has some limitations. We matched participants by gender only, and as mentioned earlier, the handball players were taller and heavier than the control participants. However, both groups presented similar body mass indexes and age, torque values were scaled to body weight, and shoulder ratios were dimensionless indexes. Thus, we believe that the selected groups were appropriate for comparisons. We did not perform an a priori power analysis. Considering our sample size of 13 handball players, a repeated measure design, and observed standard deviations from the functional ratio 60:300°/s of 0.18, the study as run had 69% power to detect a difference of 1 standard deviation, and 95% power to detect a difference of 1.5 standard deviations between dominant and non-dominant upper limbs. We failed to reach statistical significance, therefore we have effectively ruled out a difference of this size at a beta of 0.05.

Conclusion

We found that shoulder ratios at high velocity for shoulder internal rotation (i.e. functional ratio 300°/s and functional ratio 60:300°/s) were the most sensitive approaches to detect differences in shoulder ratio between upper limbs (dominant vs. non-dominant upper limb) and between groups. The functional ratio 60:300°/s appears to present some advantages over other approaches for assessing and to identify shoulder muscle torque imbalance. The functional ratio 60:300°/s showed the largest effect sizes to detect upper limb asymmetries and differences in shoulder muscle torque balance associated with throwing. Based on these findings, we recommend using the functional ratio 60:300°/s for assessing shoulder muscle imbalance.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Andrade, M. D. S., Fleury, A. M., de Lira, C. A. B., Dubas, J. P., & da Silva, A. C. (2010). Profile of isokinetic eccentric-to-concentric strength ratios of shoulder rotator muscles in elite female team handball players. *Journal of Sports Sciences, 28*, 743–749.

Beam, W. C., & Adams, G. M. (2014). Isokinetic strength. In W. C. Beam & G. M. Adams (Eds.), *Exercise physiology laboratory manual* (pp. 55–72). New York, NY: McGraw-Hill Higher Education.

Brown, L. E. (2000). *Isokinetics in human performance* (pp. 97–98). Champaign, IL: Human Kinetics.

Brown, L. E., Whitehurst, M., Findley, B. W., Gilbert, R., & Buchalter, D. N. (1995a). Isokinetic load range during shoulder rotation exercise in elite male junior tennis players. *Journal of Strength and Conditioning Research, 9*, 160–164.

Brown, L. E., Whitehurst, M., Gilbert, R., & Buchalter, D. N. (1995b). The effect of velocity and gender on load range during knee extension and flexion exercise on an isokinetic device. *Journal of Orthopaedic and Sports Physical Therapy, 21*, 107–112.
Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (pp. 223). Hillsdale, NJ: Lawrence Erlbaum.
Cook, E. E., Gray, V. I., 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.
David, G., Magarey, M. E., Jones, M. A., Dvir, Z., Türker, K. S., & Sharpe, M. (2000). EMG and strength correlates of selected shoulder muscles during rotations of the glenohumeral joint. *Clinical Biomechanics, 15*, 95–102.
Davies, G. J., & Ellenbecker, T. S. (2012). Application of isokinetics in testing and rehabilitation. In J. R. Andrews, G. L. Harrelson, & K. E. Wilk (Eds.), *Physical rehabilitation of the injured athlete* (pp. 548–570). Philadelphia, PA: Elsevier.
Debanne, T., & Laffaye, G. (2011). Predicting the throwing velocity of the ball in handball with anthropometric variables and isotonic tests. *Journal of Sports Sciences, 29*, 705–713.
Edouard, P., Degache, F., Oullion, R., Plessis, J. Y., Gleizes-Cervera, S., & Calmels, P. (2013). Shoulder strength imbalances as injury risk in handball. *International Journal of Sports Medicine, 34*, 654–660.
Ellenbecker, T., & Roetert, E. P. (2003). Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. *Journal of Science and Medicine in Sport, 6*, 63–70.
Ellenbecker, T. S., & Davies, G. J. (2000). The application of isokinetics in testing and rehabilitation of the shoulder complex. *Journal of Athletic Training, 35*, 338–350.
Ellenbecker, T. S., & Mattalino, A. J. (1997). Concentric isokinetic shoulder internal and external rotation strength in professional baseball pitchers. *Journal of Orthopaedic and Sports Physical Therapy, 25*, 323–328.
Hellwig, E. V., & Perrin, D. H. (1991). A comparison of two positions for assessing shoulder rotator peak torque: The traditional frontal plane versus the plane of the scapula. *Isokinetics and Exercise Science, 1*, 202–206.
Iga, J., George, K., Lees, A., & Reilly, T. (2009). Cross-sectional investigation of indices of isokinetic leg strength in youth soccer players and untrained individuals. *Scandinavian Journal of Medicine and Science in Sports, 19*, 714–719.
Ivey, F., Calhoun, J., Rusche, K., & Bierschenk, J. (1985). Isokinetic testing of shoulder strength: Normal values. *Archives of Physical Medicine and Rehabilitation, 66*, 384–386.
König, D. P., Bbrtram, C., & Klöttschen, R. (1995). Shoulder problems in women handball. *Journal of Shoulder and Elbow Surgery, 4*, S36.
Langevoort, G. (1996). Glenohumeral instability. In G. Langevoort (Ed.), *Sports medicine and handball* (pp. 39–44). Beckmann: Basel.
Langevoort, G., Myklebust, G., Dvorak, J., & Junge, A. (2007). Handball injuries during major international tournaments. *Scandinavian Journal of Medicine and Science in Sports, 17*, 400–407.
Laver, L., & Myklebust, G. (2015). Handball injuries: Epidemiology and injury characterization. In M. N. Doral & J. Karlsson (Eds.), *Sports injuries: Prevention, diagnosis, treatment and rehabilitation* (pp. 1–27). Berlin: Springer.
Myklebust, G., Hasslan, L., Bahr, R., & Steffen, K. (2013). High prevalence of shoulder pain among elite Norwegian female handball players. *Scandinavian Journal of Medicine and Science in Sports, 23*, 288–294.
Noffal, G. J. (2003). Isokinetic eccentric-to-concentric strength ratios of the shoulder rotator muscles in throwers and nonthrowers. *The American Journal of Sports Medicine, 31*, 537–541.
Rokito, A. S., Jobe, F. W., Pink, M. M., Perry, J., & Brault, J. (1998). Electromyographic analysis of shoulder function during the volleyball serve and spike. *Journal of Shoulder and Elbow Surgery, 7*, 256–263.
Ruas, C. V., Pinto, R. S., Cadore, E. L., & Brown, L. E. (2015). Angle specific analysis of side-to-side asymmetry in the shoulder rotators. *Sports, 3*, 236–245.
Ruas, C. V., Pinto, R. S., Hafenstine, R. W., Pereira, M. C. C., & Brown, L. E. (2014). Specific joint angle assessment of the shoulder rotators. *Isokinetics and Exercise Science, 22*, 197–204.

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 Orthopaedic and Sports Physical Therapy, 25*, 203–207.

Seil, R., Rupp, S., Tempelhof, S., & Kohn, D. (1998). Sports injuries in team handball. *The American Journal of Sports Medicine, 26*, 681–687.

Stevens, J. P. (2009). *Applied multivariate statistics for the social sciences* (pp. 166). New York, NY: Taylor & Francis Group.

Stickley, C. D., Hetzler, R. K., & Freemyer, B. G. (2008). Isokinetic peak torque ratios and shoulder injury history in adolescent female volleyball athletes. *Journal of Athletic Training, 43*, 571–577.

van den Tillaar, R., & Ettema, G. (2007). A three-dimensional analysis of overarm throwing in experienced handball players. *Journal of Applied Biomechanics, 23*, 12–19.

Wang, H.-K., Macfarlane, A., & Cochrane, T. (2000). Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *British Journal of Sports Medicine, 34*, 39–43.

Wilk, K. E., Andrews, J. R., Arrigo, C. A., Keirns, M. A., & Erber, D. J. (1993). The strength characteristics of internal and external rotator muscles in professional baseball pitchers. *The American Journal of Sports Medicine, 21*, 61–66.

Zanca, G. G., Oliveira, A. B., Saccol, M. F., Ejnisman, B., & Mattiello-Rosa, S. M. (2011). Functional torque ratios and torque curve analysis of shoulder rotations in overhead athletes with and without impingement symptoms. *Journal of Sports Sciences, 29*, 1603–1611.

Zanca, G. G., Oliveira, A. B., Saccol, M. F., & Mattiello-Rosa, S. M. (2011). Isokinetic dynamometry applied to shoulder rotators—Velocity limitations in eccentric evaluations. *Journal of Science and Medicine in Sport, 14*, 541–546.