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Shoulder functional ratio in elite junior tennis players

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ABSTRACT

Objective: To evaluate shoulder rotation strength and compare the functional ratio between shoulders of elite junior tennis players.
Design: This cross-sectional study evaluated muscular rotation performance of 40 junior tennis players (26 male and 14 female) with an isokinetic dynamometer.
Main outcome measures: Strength variables of external (ER) and internal rotators (IR) in concentric and eccentric modes were considered. For the peak torque functional ratio, the eccentric strength of the ER and the concentric strength of the IR were calculated.
Results: All variables related to IR were significantly higher on the dominant compared to the non-dominant side in males and females ($p < 0.05$), but only boys exhibited this dominance effect in ER ($p < 0.05$ and $p < 0.001$). Regarding functional ratios, they were significantly lower for the dominant shoulder ($p < 0.001$) and below 1.00 for both groups, indicating that the eccentric strength of the ER was not greater than the concentric strength of the IR.
Conclusion: Elite junior tennis players without shoulder injury have shoulder rotation muscle strength imbalances that alter the normal functional ratio between rotator cuff muscles. Although these differences do not seem to affect the athletic performance, detection and prevention with exercise programs at an early age are recommended.

1. Introduction

Isokinetic muscular concentric profiles of shoulder movements in tennis have identified sports-specific strength patterns in the dominant arm of tennis players in several previous studies (Chandler, Kibler, Stracener, Ziegler, & Pace, 1992; Ellenbecker, 1991, 1992; Silva et al., 2006). A significantly greater dominant arm concentric internal rotation strength with no bilateral difference in external rotation strength has been reported in elite, collegiate and adult tennis players (Chandler et al., 1992; Ellenbecker & Roetert, 2003; Ellenbecker, 1991, 1992; Gozlan et al., 2006; Kennedy, Altchek, & Glick, 1993; Ng & Kraemer, 1991). However, these studies provided only strength guidelines, but none of them corresponded to the functionality of the throwing motion.

During throwing, the internal rotator muscles accelerate the upper arm in a concentric action from the position of maximal external rotation to ball impact, before the external rotators eccentrically contract to decelerate this rotation during the follow-through phase of the action (Elliott, 2006). Since the posterior rotator cuff acts to decelerate and stabilize the humerus, eccentric muscular contractions play a role in athletics that is equally significant to concentric muscular contractions (Ellenbecker, Davies, & Rowinski, 1988).

Recent investigations have attempted to establish a functional relationship among the rotator cuff muscles (Niederbracht, Shim, Sloniger, Paternostro-Bayles, & Short, 2008; Noffal, 2003; Scoville, Arciero, Taylor, & Stoneman, 1997; Yildiz et al., 2006), including a "functional ratio" involving eccentric testing of the shoulder external rotator muscles and concentric testing of the internal rotator muscles (Scoville et al., 1997). Previous studies of overhead sports reported ratios ranging from 1.08 to 1.17 for the dominant shoulder, supporting the argument that eccentric external rotation torque should be greater than concentric internal torque (Ng & Lam, 2002; Noffal, 2003; Scoville et al., 1997; Yildiz et al., 2006). This difference is necessary to overcome and to decelerate not only the strength of the concentrically active internal rotators but also the other segmental forces associated with the dynamic nature of the throwing motion (Noffal, 2003).

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To the best of our knowledge, no study has evaluated this functional isokinetic profile of tennis player's strength. This is extremely useful to improve performance, and is also important for prevention and rehabilitation of injuries, especially in younger tennis players. Therefore, our aim was to evaluate the performance of concentric and eccentric muscular rotators and compare the functional ratio between dominant and non-dominant shoulders of elite junior tennis players.

2. Methods

Forty junior tennis players (26 male, 14 female) with a mean age of 14 years (range, 12–18) were evaluated. For male and female players, mean (SD) weight was 57.9 (15) and 53.9 (9.3) kg, respectively, and mean (SD) height was 168 (14) and 163 (5) cm. To take part in the study, a tennis player had to belong to the Brazilian Tennis Confederation as a junior, be among the 50 best players in his/her category, and have no pathology in the dominant or non-dominant shoulder. All athletes agreed to participate in the study on a voluntary basis, and their legal guardians signed an informed consent. The Committee on Ethical Research of the Federal University of São Paulo approved all procedures described in this study.

Evaluations were performed with an isokinetic dynamometer (Cybex 6000; Cybex, Ronkonkoma, New York, USA) and before testing, players were allowed a 5-min warm up at 60 W on a Cybex arm ergometric device, followed by specific stretching exercises for the shoulder. After the warm up, they were positioned supine on the upper-body testing table and stabilized with bandages around the thorax and waist. Shoulder internal and external rotation performance were measured using reciprocal motions of internal and external rotation with the shoulder in 90° of glenohumeral joint abduction in the coronal plane and the elbow at 90° flexion (Fig. 1). Isokinetic testing was performed with 0–60° of external rotation and 0–60° of internal rotation, because correction for gravity is not possible.

The internal and external rotator muscle strength of the dominant and non-dominant shoulders were tested at 60°/s and 180°/s angular velocities, first concentrically and then eccentrically. The sequence performed for each speed consisted of three sub maximum repetitions of the movement for familiarization, followed by five repetitions at 60°/s and then five repetitions at 180°/s, with a 1-min rest between sets. For all athletes, only the side of test (dominant or non-dominant) was randomized.

The variables analyzed from the isokinetic dynamometer tests were peak torque in relation to body weight (PT/BW), total work relative to body weight (TW/BW), and average power in relation to body weight (AVG/BW). The peak torque (PT), total work (TW) and average power (AVG) ratios between external and internal rotators (ER/IR) of concentric and eccentric mode were also analyzed. For the PT functional ratio, we calculated eccentric strength of the external rotator and concentric strength of the internal rotator (ERecc/IRcon).

Values are given as mean ± standard deviation (SD) and comparisons were made for dominance and sex. The statistical analysis included paired samples *t* tests and an analysis of variance with repeated measures. All statistical analyses were performed using the statistical package SPSS for Windows (version 13.0) and a *p*-value of <0.05 was considered statistically significant.

3. Results

Data were significantly different for males and females in all variables studied, with male players showing better performance than female players. In both sexes, all variables related to internal rotation strength in the dominant shoulder were significantly greater than the non-dominant shoulder at both testing speeds ($p < 0.05$ and $p < 0.001$) and concentric (Table 1) and eccentric modes (Table 2). Regarding external rotation strength performance, only males exhibited a dominance effect for concentric ($p < 0.001$) and eccentric modes ($p < 0.05$).

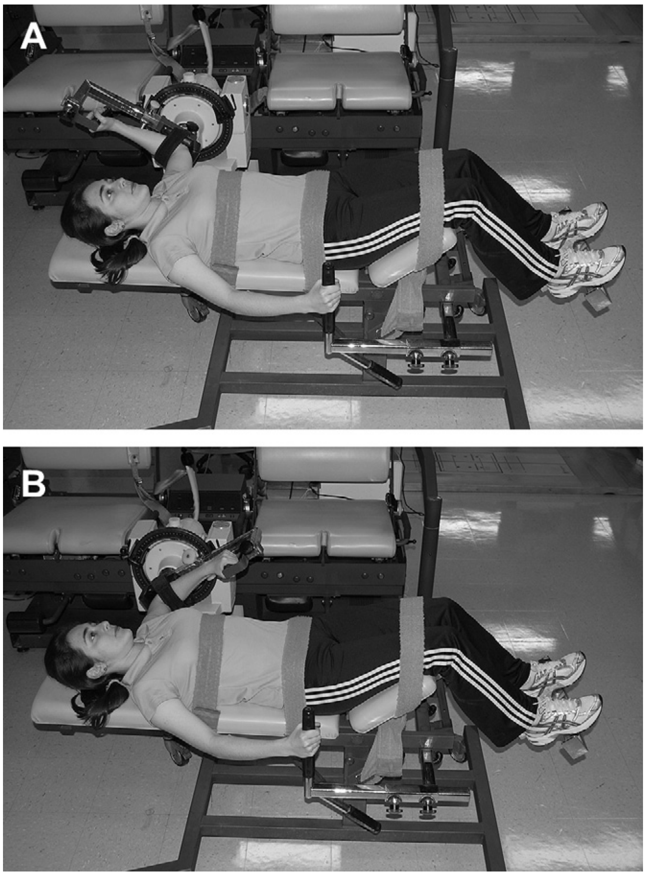

Fig. 1. Isokinetic strength testing position with trunk and waist stabilized. The testing of shoulder external and internal rotator muscles is performed with the athlete in supine, 90° of shoulder abduction and 90° of elbow flexion. A, external rotation; B, internal rotation. The subject has given permission for publication of this figure.

Concentric, eccentric and functional ratios of external to internal rotator strength are presented in Table 3. Females exhibited a dominance effect in all evaluated variables, with higher ratios for the non-dominant side. The ratios of eccentric external rotation to concentric internal rotation showed a similar pattern, with boys and girls presenting functional ratios significantly lower for dominant than non-dominant shoulders ($p < 0.05$ and $p < 0.001$).

4. Discussion

The main findings of our study were that male junior tennis players had greater external rotation strength in the dominant arm, and both male and female players exhibited a dominance effect in internal rotation strength. Despite these gains, the lower functional ratio in dominant shoulder showed that elite junior tennis players have muscle strength imbalances that could lead to shoulder injuries.

For all measurements of internal rotation strength, the dominant shoulder of male and female tennis players was stronger than the non-dominant shoulder. This is consistent with the tennis training demands and it is considered an adaptation to the serving motion (Ellenbecker et al., 1988; Ellenbecker & Roetert, 2003; Ellenbecker, 1991, 1992; Gozlan et al., 2006).

Table 1
Isokinetic concentric external and internal rotation strength in elite junior tennis players. Data are presented as means ± SD.

Concentric	Boys ($n = 26$)		Girls ($n = 14$)	
	Dominant	Non-dominant	Dominant	Non-dominant
External rotation				
PT/BW at 60°/s	38.1 ± 6[a]	35.2 ± 6.7	30.3 ± 5.6	27.3 ± 5.1
PT/BW at 180°/s	33.1 ± 6.1[a]	29.7 ± 6.8	24.2 ± 4.1	23.2 ± 4.9
TW/BW at 60°/s	56.7 ± 14.5[a]	50.3 ± 14.8	42.7 ± 11.2	36.1 ± 7.5
TW/BW at 180°/s	49.7 ± 13.7[a]	43.5 ± 11.9	33.8 ± 9.5	29.9 ± 9.4
AVG/BW at 60°/s	26.9 ± 6.9[a]	24.1 ± 7.4	20.5 ± 5.9	16.6 ± 4.2
AVG/BW at 180°/s	70.6 ± 18.6[a]	60.1 ± 18	48 ± 14.1	41 ± 14.3
Internal rotation[b]				
PT/BW at 60°/s	48.3 ± 9.1	40.9 ± 9	40.2 ± 5.9	27.9 ± 5.6
PT/BW at 180°/s	42.6 ± 9.5	35.8 ± 8.4	35.4 ± 5	24.4 ± 4.9
TW/BW at 60°/s	79.4 ± 18.4	64.6 ± 17.3	64 ± 10.1	41.4 ± 11.2
TW/BW at 180°/s	66 ± 18.7	53.8 ± 14.1	53.4 ± 10.3	33.7 ± 8.9
AVG/BW at 60°/s	38.2 ± 8.8	31.3 ± 9.3	30.7 ± 5.2	19.4 ± 5.3
AVG/BW at 180°/s	92.2 ± 26.5	76.4 ± 21.4	76.9 ± 15.5	47 ± 12.6

PT/BW: peak torque in relation to body weight in *N* m per kg body mass.
TW/BW: total work in relation to body weight in joules per kg body mass.
AVG/BW: average power in relation to body weight in watts per kg body weight.
[a] Statistically significant difference between dominant and non-dominant side ($p < 0.001$).
[b] All values of dominant concentric internal rotation were statistically significant different from those of non-dominant concentric internal rotation ($p < 0.05$).

Although there is an undeniable role of internal rotation strength in the dominant shoulder in the service and forehand strokes in tennis (Elliott, 2006), the strength of the external rotators is essential for glenohumeral stability. There is no previous research that reports a dominance effect in male athletes for the external rotators in concentric ($p < 0.001$) and eccentric ($p < 0.05$) modes. We found only two studies that reported this finding in female tennis players: one with amateur-league (Stanley, McGann, Hall, McKenna, & Briffa, 2004) and the other with a sample of highly skilled females (Ellenbecker, 1992). This relatively higher strength of external rotators by itself does not represent much, since the prevention of shoulder injuries must be based on ratios between external and internal rotators in dominant shoulder.

Table 2
Isokinetic eccentric external and internal rotation strength in elite junior tennis players. Data are presented as means ± SD.

Eccentric	Boys ($n = 26$)		Girls ($n = 14$)	
	Dominant	Non-dominant	Dominant	Non-dominant
External rotation				
PT/BW at 60°/s	43.2 ± 9.3[a]	39 ± 7.7	36.1 ± 6.3[a]	31.1 ± 5.2
PT/BW at 180°/s	45.3 ± 8.3[a]	41.6 ± 7.9	36.1 ± 4.2	35.5 ± 7.8
TW/BW at 60°/s	61.2 ± 18.7	57.2 ± 16.3	46.6 ± 11.6	41.6 ± 9.6
TW/BW at 180°/s	61.2 ± 19.2	56.6 ± 15.2	46.4 ± 7.8	46.3 ± 14.4
AVG/BW at 60°/s	28.1 ± 8.7	25.9 ± 7	21.7 ± 5.1	19.9 ± 4.3
AVG/BW at 180°/s	83.8 ± 24.6[a]	71.1 ± 19.2	62.2 ± 9.9	61.7 ± 16.8
Internal rotation[b]				
PT/BW at 60°/s	53.8 ± 14.6	42.7 ± 10.9	41.8 ± 7.6	30.9 ± 8.4
PT/BW at 180°/s	49.6 ± 14	43,2 ± 8.5	41.6 ± 7.8	31.9 ± 8.2
TW/BW at 60°/s	75.4 ± 44.2	62.7 ± 30.1	63.9 ± 12.6	45.5 ± 16.5
TW/BW at 180°/s	75.3 ± 28	64.6 ± 19	62.9 ± 15.2	45.1 ± 17.6
AVG/BW at 60°/s	37 ± 11.5	29.6 ± 9	29.4 ± 7.1	20.4 ± 7.9
AVG/BW at 180°/s	97.6 ± 35.4	85.4 ± 24.3	83.1 ± 18.3	59.7 ± 23

PT/BW: peak torque in relation to body weight in N m per kg body mass.
TW/BW: total work in relation to body weight in joules per kg body mass.
AVG/BW: average power in relation to body weight in watts per kg body weight.
[a] Statistically significant difference between dominant and non-dominant side ($p < 0.05$).
[b] All values of dominant eccentric internal rotation were statistically significant different from those of non-dominant eccentric internal rotation ($p < 0.05$ and $p < 0.001$).

Table 3
Isokinetic strength ratio between external and internal rotation (ER/IR) in elite junior tennis players. Data are presented as means ± SD.

	Boys ($n = 26$)		Girls ($n = 14$)	
	Dominant	Non-dominant	Dominant	Non-dominant
Concentric ER/IR				
PT at 60°/s	0.80 ± 0.14	0.86 ± 0.09[a]	0.75 ± 0.13	0.97 ± 0.11[b]
PT at 180°/s	0.79 ± 0.14	0.83 ± 0.10	0.68 ± 0.07	0.96 ± 0.18[b]
TW at 60°/s	0.72 ± 0.15	0.78 ± 0.11	0.65 ± 0.10	0.89 ± 0.14[a]
TW at 180°/s	0.77 ± 0.15	0.81 ± 0.13	0.63 ± 0.11	0.88 ± 0.18[b]
AVG at 60°/s	0.71 ± 0.15	0.77 ± 0.11	0.66 ± 0.11	0.87 ± 0.17[a]
AVG at 180°/s	0.78 ± 0.17	0.79 ± 0.15	0.62 ± 0.11	0.87 ± 0.20[b]
Eccentric ER/IR				
PT at 60°/s	0.83 ± 0.21	0.93 ± 0.17	0.87 ± 0.15	1.02 ± 0.13[a]
PT at 180°/s	0.94 ± 0.20	0.97 ± 0.15	0.88 ± 0.15	1.12 ± 0.15[b]
TW at 60°/s	0.76 ± 0.17	0.87 ± 0.15[a]	0.73 ± 0.14	0.96 ± 0.17[a]
TW at 180°/s	0.87 ± 0.22	0.85 ± 0.16	0.76 ± 0.20	1.07 ± 0.18[b]
AVG at 60°/s	0.76 ± 0.19	0.90 ± 0.18[a]	0.75 ± 0.18	1.04 ± 0.22[a]
AVG at 180°/s	0.89 ± 0.25	0.84 ± 0.14	0.77 ± 0.2	1.08 ± 0.21[b]
Functional ratio: eccentric ER/concentric IR				
PT at 60°/s	0.84 ± 0.42	1.11 ± 0.31[a]	0.91 ± 0.12	1.03 ± 0.13[a]
PT at 180°/s	0.97 ± 0.16	1.2 ± 0.29[b]	1.12 ± 0.16	1.45 ± 0.16[b]

PT: peak torque.
TW: total work.
AVG: average power.
[a] Value of non-dominant strength ratio were statistically significant different from those of dominant strength ratio ($p < 0.05$).
[b] Value of non-dominant strength ratio were statistically significant different from those of dominant strength ratio ($p < 0.001$).

The ratio values recommended to provide muscular balance are between 66 and 75%, such that external rotators are at least 2/3 the strength of the internal rotators in the concentric mode (Ellenbecker & Davies, 2000). For concentric and eccentric ratios, dominance had an effect for girls and not for boys: the means on the dominant side were significantly lower than those on the non-dominant side ($p < 0.001$). This decrease is produced by greater relative internal rotation strength development, and the dominant concentric ratios are in agreement with other studies of normal subjects (Chandler et al., 1992; Ellenbecker & Roetert, 2003; Ellenbecker, 1991, 1992; Ellenbecker & Davies, 2000). Although external rotators of the dominant side were greater than those of the non-dominant side for boys, the concentric ratio between external and internal rotation remains in a range that is considered safe.

The role of the antagonist muscle is to fire in an eccentric manner to decelerate the motion of the agonist (Scoville et al., 1997; Yildiz et al., 2006). For medial rotation, this refers to the lateral rotators firing eccentrically (antagonists) to decelerate the concentrically firing medial rotators (agonists). In athletes, a proper ratio of the eccentric antagonist to the concentric agonist muscles is critical for dynamic stability and optimal function (Scoville et al., 1997). Because eccentric antagonists should be sufficiently strong to overcome and decelerate the agonists and forces accompanying the motion, a ratio greater than 1:1 would be expected, and studies with functional ratios have demonstrated values ranging from 1.08 to 1.17 (Ng & Lam, 2002; Noffal, 2003; Scoville et al., 1997; Yildiz et al., 2006). These higher ratios are a function of greater external rotation eccentric force production compared with concentric force at the same velocity (Ellenbecker et al., 1988).

Our ratios of ERecc/IRcon on the dominant side were lower than 1, indicating that the eccentric strength of the external rotator muscles was not greater than the concentric strength of the internal rotator muscles. A greater eccentric strength is necessary to decelerate the rapidly moving upper limb (Scoville et al., 1997; Yildiz et al., 2006) and can be achieved with specific training (Niederbracht et al., 2008).

Functional ratios for the dominant shoulder were significantly lower than for the non-dominant shoulder ($p < 0.001$). This discrepancy was also found by Yildiz et al. (2006), and explained as a decrease in eccentric external rotation strength or an increase in concentric internal rotation strength, or a combination of both. Based on our data, girls had significantly higher concentric strength in dominant internal rotators, without differences in the external rotators, explaining the lower dominant functional ratio. Boys had strength gains in the dominant throwing shoulder for both concentric internal rotation and eccentric external rotation, lowering the dominant shoulder functional ratio, since the gains in eccentric external rotation are not sufficient to overcome internal rotational gains.

Injuries in tennis are often associated with alterations in the energy flow across segments of the kinetic chain, and as a part of this mechanism intact dynamic and static stabilizers of the shoulder are necessary (Elliott, 2006; van der Hoeven & Kibler, 2006). Our study demonstrated that elite junior tennis players have rotational strength adaptations that alter the functional ratio on the dominant side, and these imbalances could lead to injuries. Restoration of shoulder adaptations to a safe level involves exercises to strengthen the external rotators without simultaneous gains to the internal rotator muscles, and also scapulothoracic musculature for position and control of the scapula on the thorax (Phadke, Camargo, & Ludewig, 2009; Silva, Hartmann, Laurino, & Biló, 2008). Recently, a specific strength-training program resulted in a decrease in shoulder rotator imbalance by successfully targeting the external rotator muscles (Niederbracht et al., 2008).

5. Conclusions

Elite junior tennis players without shoulder injury have shoulder rotation muscle strength imbalances that alter the normal functional ratio between the rotator cuff muscles. These differences in strength do not seem to affect athletic performance, but detection and prevention with exercise programs at an early age are recommended.

Conflict of interest statement

There were no conflicts of interest for the authors of this manuscript.

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Ethical approval statement

All athletes agreed to participate in the study on a voluntary basis, and their legal guardians signed an informed consent approved by the Committee on Ethical Research of the Federal University of São Paulo (CEP n°2042/07).

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