ORIGINAL ARTICLE

Shoulder strength profile in elite junior tennis players: horizontal adduction and abduction isokinetic evaluation

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Objective: To establish normative data for muscle performance during isokinetic horizontal abduction and adduction of the shoulder in elite junior tennis players.

Methods: Thirty six tennis players were evaluated (23 male, 13 female; mean age 14 years (range 12-18)). An isokinetic dynamometer was used to test the shoulder horizontal abductors and adductors at 60 and 180°/s. Absolute and relative peak torque (PT and PT/BW), total work (TW), endurance ratio (ER), and the ratio of the peak torque between horizontal abductors and adductors (HAB/HAD ratio) were recorded. Data were compared for the dominant and non-dominant shoulders, horizontal abductor and adductor muscles, and between players grouped according to age.

Results: The dominant shoulder was significantly ($p < 0.05$) stronger than the non-dominant shoulder in all variables except ER and HAB/HAD ratio. The abductors were significantly ($p < 0.05$) weaker than the adductors in all subjects. The type of backhand (one handed or two handed) did not influence the strength of the shoulder horizontal abductors on the dominant side. The number of years of tennis practice had an effect on muscle strength as evaluated by absolute data (PT and TW) but not relative measurements (PT/BW and TW/BW).

Conclusion: The findings confirm that horizontal abduction and adduction are stronger in the dominant shoulder of junior tennis players. The clinical relevance of these findings is not established, and more studies are needed to compare tennis players with athletes from other sports and non-athletes.

Tennis involves major overloading of the shoulder,¹ so players need appropriate muscular balance to avoid lesions.² Several studies have identified the shoulder as a common site of injury in tennis players caused by repetitive stress on this joint during training and matches in both adult³⁻⁴ and junior⁵⁻⁸ players.

Several methods have been used to examine the muscle profile of the shoulder, including clinical analysis of muscle atrophy and volumetric measurements of the arm.⁹ Isokinetic evaluations are more reliable in terms of qualitative and quantitative analysis, and specific adaptive functions have been found in both male and female tennis players.¹⁻¹⁰⁻¹⁸ These studies predominantly evaluated movements that occur during the serve, through measures of internal and external shoulder rotation and flexion and extension movements.

There are few studies in the literature on muscle movements during the forehand and backhand strokes. We do know that, in the acceleration phase, the forehand involves high muscular activity, predominantly in the brachial biceps, subscapularis, pectoralis major, and serratus anterior.²⁻⁵ During the same phase of the backhand, the middle deltoid, supraspinatus and infraspinatus muscles are predominantly involved.²⁻⁵ There is less activity in the brachial biceps, serratus anterior, and dorsalis major during the backhand acceleration phase.² These muscles, although involved in several movements of the shoulder girdle and trunk, are important shoulder adductors and abductors, particularly the pectoralis major (adductor) and the middle deltoid (abductor).

Building an isokinetic profile of a tennis player's strength may be extremely useful in improving performance, and is

also important for prevention and rehabilitation of tennis injuries.¹⁹ Although several studies have shown the importance of this in relation to the shoulder rotators,¹⁴⁻¹⁵ so far no research has evaluated the strength of horizontal shoulder abductors and adductors.

The aim of this study was to perform an isokinetic evaluation of horizontal shoulder abduction and adduction movements in junior elite tennis players to build a profile of concentric isokinetic muscular performance.

MATERIALS AND METHODS

The subjects evaluated were 36 junior tennis players (23 male, 13 female) with a mean age of 14 years (range 12-18). Mean (SD) weight was 59.8 (14.5) and 52.8 (8.6) kg for the male and female players respectively, and mean (SD) height was 170 (14) and 162 (5) cm. To take part in the study, tennis players 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 shoulders. A consent form was signed by their legal guardians agreeing to voluntarily participation in the study, in accordance with the rules of the university's ethics committee. The ethics committee of the Federal University of São Paulo also officially approved the study.

Before evaluation, athletes answered a questionnaire on arm dominance, type of backhand, and hours a week spent playing tennis and training on court. The following results

Abbreviations: PT, absolute peak torque in N.m; PT/BW, peak torque in relation to body weight in N.m per kg body mass; TW, absolute total work in joules; ER, endurance ratio; HAB/HAD ratio, peak torque ratio between horizontal shoulder abductors and adductors

Figure 1 Start position for the horizontal adduction test. The subject is stabilised with bandages around the thorax and waist. The subject has given permission for publication of this figure.

were obtained: 89% of players were right handed; 81% used both hands for the backhand; mean (SD) age at which they started to play tennis was 8.4 (2.3) years (range 4–13 years); mean (SD) length of time for which they had been playing was 6.3 (2.6) years (range 2–12 years); mean (SD) on-court training time was 11.5 (6.2) hours/week (range 5–30).

Evaluations were performed with an isokinetic dynamometer (Cybex 6000; Cybex, Ronkonkoma, New York, USA). Subjects were allowed a five minute warm up at 60 W on a Cybex brand 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 stabilised with bandages around the thorax and waist (figs 1 and 2). Because of the position of the subjects during the evaluation, we performed gravity correction before testing and determined the range of motion from 10° of horizontal adduction to 70° of horizontal abduction (80° range of movement). Horizontal shoulder abductors and adductors were tested at 60 and 180°/s concentrically for both upper limbs. The sequence performed for each speed was: three submaximum repetitions of the movement for familiarisation, followed by five repetitions at 60°/s and 20 repetitions at 180°/s, with a one minute rest between sets.

The muscle performance descriptive data analysed in this study were absolute peak torque (PT) in N.m, peak torque in relation to body weight (PT/BW) in N.m per kg body mass, absolute total work (TW) in joules, endurance ratio (ER) of horizontal abductors and adductors, and peak torque ratio between horizontal shoulder abductors and adductors (HAB/HAD ratio). These data were generated using the Cybex 6000 program, and comparisons were made between dominant and non-dominant limb, between horizontal abductors and adductors, and across the groups of players.

Statistical analysis

Qualitative variables are given as absolute and relative frequency (%), and quantitative ones as mean (SD) and minimum and maximum values.

For each movement evaluated (abduction and adduction), an analysis of variance model was used for repeated measures with two repeated factors, dominance with two levels (dominant and non-dominant) and speed with two levels (60 and 180°/s), to evaluate the effect of these factors on the variables PT, PT/BW, TW, TW/BW, and HAB/HAD ratio.

Figure 2 Final position for the adduction test and start position for the horizontal abduction test. The subject has given permission for publication of this figure.

In the analysis of ER, an analysis of variance model was used for repeated measures with one factor (arm dominance) with two levels (left handed and right handed).

A significance level of 0.05 was used ($\alpha = 5\%$).

RESULTS

For all the subjects, the means of all variables evaluating horizontal abduction and adduction movements were significantly higher on the dominant than the non-dominant side except for ER. For horizontal abduction, there was a significant effect of the dominance factor on the variables PT ($p = 0.005$), PT/BW ($p = 0.001$), TW ($p = 0.001$), and TW/BW ($p < 0.001$), and a significant effect of the speed factor for all the variables (all $p < 0.001$). For horizontal adduction, there was a significant effect of dominance for PT, PT/BW, TW, and TW/BW (all $p < 0.001$) and a significant effect of speed for PT/BW, TW, and TW/BW (all $p < 0.05$). For the HAB/HAD ratio, a significant effect was found only for speed ($p < 0.001$): the means at 60°/s was significantly higher than at 180°/s. Table 1 shows comparative data for boys and girls.

At all the levels studied, data were significant for dominance and sex: male players showed better results than female players. The exceptions were the analysis of ER, which was significantly ($p = 0.023$) higher in the male players only for adduction movements, and HAB/HAD ratio, which showed no significant effect of dominance.

We compared data by backhand type (six one handed and 17 two handed) in the male players. For abduction, we found significant effects of dominance for PT ($p = 0.032$), PT/BW ($p = 0.019$), and TW/BW ($p = 0.040$), and significant effects of speed for all the variables tested (all $p < 0.05$). For adduction, we found significant effects of dominance on PT ($p < 0.001$), PT/BW ($p < 0.001$), TW ($p = 0.002$), and TW/BW

Table 1. Peak torque (PT), peak torque over body weight (PT/BW; body weight in kg), total work (TW), total work over body weight (TW/BW), and endurance ratio (ER) of horizontal abductors and adductors and peak torque ratios between shoulder horizontal abductors and adductors in junior tennis players

	Boys (n = 23)		Girls (n = 13)	
	Dominant	Non-dominant	Dominant	Non-dominant
Horizontal abduction				
PT at 60°/s	42.5 (15.2)	40.6 (15.0)	32.2 (7.7)	28.7 (7.5)
PT at 180°/s	39.6 (16.5)	35.9 (14.5)	24.5 (6.5)	23.7 (6.9)
PT/BW at 60°/s	69.8 (15.0)	66.3 (13.1)	60.5 (10.1)	53.7 (9.6)
PT/BW at 180°/s	64.5 (17.3)	58.5 (13.7)	45.9 (8.2)	44.1 (8.7)
TW at 60°/s	42.1 (18.4)	37.4 (14.8)	32.2 (8.8)	27.2 (8.1)
TW at 180°/s	28.2 (17.7)	24.4 (13.5)	17.1 (7.9)	15.2 (8.3)
TW/BW at 60°/s	69.5 (21.8)	61.4 (16.1)	60.2 (10.5)	50.5 (9.3)
TW/BW at 180°/s	45.5 (22.9)	39.4 (16.8)	31.4 (12.1)	27.5 (12.3)
ER at 180°/s (%)	96.6 (13.3)	107.0 (25.0)	96.4 (27.6)	91.5 (30.5)
Horizontal adduction				
PT at 60°/s	56.0 (22.7)	49.9 (19.4)	37.5 (8.4)	33.2 (6.7)
PT at 180°/s	56.2 (23.5)	50.4 (21.1)	32.7 (9.5)	29.6 (7.9)
PT/BW at 60°/s	90.9 (21.3)	81.1 (17.8)	70.4 (10.5)	62.7 (9.9)
PT/BW at 180°/s	90.4 (22.9)	81.4 (20.0)	60.8 (12.9)	55.7 (12.0)
TW at 60°/s	58.0 (26.3)	51.0 (22.4)	41.0 (11.6)	34.5 (7.4)
TW at 180°/s	43.4 (23.4)	37.1 (20.3)	24.3 (10.7)	19.4 (8.2)
TW/BW at 60°/s	93.5 (28.7)	82.6 (23.9)	76.6 (15.7)	65.4 (11.8)
TW/BW at 180°/s	68.5 (28.1)	59.0 (24.1)	44.5 (16.9)	35.9 (13.4)
ER at 180°/s (%)	88.8 (11.7)	90.8 (11.4)	87.1 (21.0)	73.3 (20.7)
Abduction/adduction				
PT at 60°/s (%)	77.1 (8.4)	82.5 (12.7)	86.4 (11.0)	85.7 (11.4)
PT at 180°/s (%)	71.9 (13.3)	72.6 (12.3)	76.8 (15.5)	79.6 (11.2)

Values are mean (SD).

($p = 0.002$), and significant effects of speed on TW and TW/BW (both $p < 0.05$). For the HAB/HAD ratio, we found a significant ($p = 0.005$) effect of speed, for which the means for 60°/s are significantly higher than for 180°/s. We found no significant difference between any of the variables studied between players with one handed and two handed back-hands.

Table 2 shows the breakdown for the 11–14 ($n = 15$) and 15–18 ($n = 21$) age groups. For all variables, mean values for

the dominant side were significantly higher than for the non-dominant side. Mean values for the 15–18 year olds were significantly higher than for the 11–14 year olds, except for TW/BW. ER showed no significant effect for dominance or age, and for the HAB/HAD ratio, the only significant effect was for speed.

We grouped players according to the number of years that they had played tennis: those who had played for less than six years ($n = 19$) and those who had played for more than

Table 2 Peak torque (PT), peak torque over body weight (PT/BW; body weight in kg), total work (TW), total work over body weight (TW/BW), and endurance ratio (ER) of horizontal shoulder abductors and adductors and peak torque ratio between horizontal abductors and adductors in 11–14 year old and 15–18 year old players

	11–14 year olds (n = 15)		15–18 year olds (n = 21)	
	Dominant	Non-dominant	Dominant	Non-dominant
Horizontal abduction				
PT at 60°/s	28.7 (7.9)	27.5 (9.2)	46.0 (12.7)	42.6 (13.4)
PT at 180°/s	23.2 (6.5)	22.0 (6.2)	41.9 (15.5)	38.3 (13.4)
PT/BW at 60°/s	62.1 (11.5)	58.3 (9.8)	69.6 (15.1)	64.1 (15.1)
PT/BW at 180°/s	50.7 (12.5)	47.3 (9.3)	62.8 (18.5)	57.5 (15.3)
TW at 60°/s	28.2 (7.6)	25.6 (8.4)	45.9 (16.7)	39.4 (13.8)
TW at 180°/s	15.0 (6.0)	13.0 (6.0)	30.8 (17.3)	26.9 (13.0)
TW/BW at 60°/s	61.5 (14.9)	54.7 (11.8)	69.4 (21.0)	59.4 (16.7)
TW/BW at 180°/s	33.0 (14.1)	28.1 (12.1)	45.7 (23.2)	40.0 (17.1)
ER at 180°/s (%)	97.2 (25.4)	96.7 (35.4)	96.0 (14.1)	104.8 (21.0)
Horizontal adduction				
PT at 60°/s	34.5 (10.3)	30.7 (7.5)	59.9 (19.9)	53.2 (17.2)
PT at 180°/s	32.0 (12.3)	28.9 (7.2)	58.9 (21.6)	52.8 (20.5)
PT/BW at 60°/s	73.9 (12.3)	66.4 (10.1)	90.3 (22.7)	80.2 (19.9)
PT/BW at 180°/s	67.6 (16.2)	62.7 (11.1)	88.3 (25.8)	78.9 (24.5)
TW at 60°/s	35.6 (12.6)	31.5 (8.3)	63.4 (22.6)	54.7 (20.3)
TW at 180°/s	22.2 (10.3)	18.1 (6.9)	46.7 (22.1)	39.7 (19.6)
TW/BW at 60°/s	75.9 (17.3)	67.9 (12.9)	95.6 (28.1)	82.4 (25.0)
TW/BW at 180°/s	46.2 (16.4)	38.7 (13.1)	69.6 (29.1)	59.1 (25.8)
ER at 180°/s (%)	85.6 (21.9)	81.9 (16.5)	90.1 (8.5)	86.3 (18.1)
Abduction/adduction				
PT at 60°/s (%)	84.0 (10.4)	87.8 (11.6)	77.9 (9.7)	80.7 (11.9)
PT at 180°/s (%)	76.3 (17.2)	75.7 (12.1)	71.8 (11.4)	74.7 (12.6)

Values are mean (SD).

six years ($n = 17$) (table 3). For all variables, mean values for the dominant side were significantly higher than for the non-dominant side. The mean values in the group with less than six years playing experience were significantly lower than those in the group with more than six years experience. The exceptions were PT/BW for abductors and adductors and TW/BW for abductors. Dominance and years playing tennis had no significant effect for ER and HAB/HAD ratio.

DISCUSSION

Shoulder injuries are very common in junior competitive tennis players, but we lack good data for developing prevention strategies.

Isokinetic evaluation has proved to be a good method for muscle assessment, and several studies in the literature have set normative criteria for rotational shoulder movements, for which we know that there is a significant difference between the dominant and non-dominant limb that it is characteristic of tennis. Our study is the first to propose evaluating horizontal adduction and abduction of the shoulder in this population, as there are no data available for junior competitive tennis players.

Our sample consisted of male and female junior tennis players. As expected, the boys were stronger than the girls.

Our main goal was to study horizontal adduction and abduction movements, as specific data have not been reported in the literature. Furthermore, these movements are involved in all baseline strokes. Ryu *et al*¹³ noted that the shoulder adductors and abductors are much involved in tennis, particularly during the acceleration phase of forehand and backhand.

Because of the different backhand techniques and its muscle patterns, we compared one handed with two handed backhand players. The boys that used a one handed backhand did not use any more force in the dominant limb than those who used a two handed backhand. (We were unable to perform this analysis for the girls because only one

of the 13 girls used a one handed backhand.) This may be explained by the importance of trunk rotation in the generation of power for the two handed backhand; the power is generated at the core, and not at the shoulder girdle, as in many other tennis strokes.

In the overall analysis of the data, we noted that, for practically all the variables studied, the dominant limb was stronger than the non-dominant limb, except for ER and HAB/HAD ratio. ER is a good indicator of muscle fatigue, but because of the position of the subject during the test, compensation can occur through muscular activation in other places, such as the trunk, which may give the false impression of no muscle fatigue. Despite stabilisation of the trunk and abdomen, as the subject performs more repetitions, the trunk may start to compensate for fatigue in the shoulder musculature. One finding that we were unable to explain was the ER of about 107% in the non-dominant limb.

In a study of 24 male baseball players, Alderink and Kuck¹⁰ did not find any significant difference between the dominant and non-dominant limbs in horizontal adduction and abduction movements. Furthermore, they noted that the adductors and abductors were almost equal in strength, unlike our own sample in which the abductors were always weaker (about 20% for the dominant side and 25% for the non-dominant side). We believe that this is because forehands and backhands, which are the strokes most often performed by tennis players during training and matches, require greater generation of power for the horizontal adduction of the shoulder, particularly during the acceleration phase.

Other authors have studied horizontal adduction and abduction movements in relation to age, but in other sports. Weir *et al*¹⁹ examined wrestlers and found that absolute and relative peak torque during testing increased with age at low (30°/s) and moderate (180°/s) speeds, but not at high speed (300°/s). We obtained similar data in our sample. The mean values for the 15–18 age group were significantly higher than

Table 3 Peak torque (PT), peak torque over body weight (PT/BW; body weight in kg), total work (TW), total work over body weight (TW/BW), and endurance ratio (ER) for horizontal shoulder abductors and adductors and peak torque ratios between horizontal abductors and adductors in tennis players who had been playing tennis for less than six years ($n = 19$) or more than six years ($n = 17$)

	Less than 6 years ($n = 19$)		More than 6 years ($n = 17$)	
	Dominant	Non-dominant	Dominant	Non-dominant
Horizontal abduction				
PT at 60°/s	33.2 (12.9)	29.6 (10.0)	45.1 (12.4)	43.8 (14.1)
PT at 180°/s	29.5 (14.4)	25.9 (10.2)	39.3 (15.5)	37.8 (14.4)
PT/BW at 60°/s	64.5 (14.1)	57.7 (10.4)	68.6 (14.1)	66.2 (15.0)
PT/BW at 180°/s	56.6 (17.0)	50.2 (11.3)	59.1 (17.7)	56.8 (16.0)
TW at 60°/s	32.1 (13.8)	26.7 (10.3)	45.7 (13.8)	41.5 (12.7)
TW at 180°/s	20.1 (15.0)	16.3 (9.9)	28.8 (15.6)	26.5 (13.4)
TW/BW at 60°/s	62.8 (20.9)	52.5 (13.9)	69.9 (16.2)	62.9 (14.3)
TW/BW at 180°/s	37.8 (21.0)	30.8 (14.2)	43.2 (20.6)	39.8 (17.4)
ER at 180°/s (%)	97.6 (22.3)	99.7 (29.4)	95.3 (15.9)	103.3 (26.5)
Horizontal adduction				
PT at 60°/s	40.1 (16.3)	36.7 (14.6)	59.7 (20.6)	51.9 (18.1)
PT at 180°/s	38.2 (18.6)	34.4 (15.9)	58.3 (22.2)	52.3 (20.4)
PT/BW at 60°/s	77.4 (16.8)	71.1 (15.4)	90.3 (22.7)	78.3 (19.7)
PT/BW at 180°/s	72.7 (21.7)	66.6 (19.0)	87.5 (25.4)	78.4 (22.7)
TW at 60°/s	40.4 (19.7)	36.3 (15.6)	64.6 (21.0)	54.8 (20.1)
TW at 180°/s	27.6 (19.4)	23.3 (15.6)	46.4 (20.1)	39.0 (19.1)
TW/BW at 60°/s	77.7 (23.0)	70.4 (18.6)	98.2 (25.3)	83.0 (23.8)
TW/BW at 180°/s	51.2 (26.3)	43.8 (21.4)	69.5 (25.1)	58.3 (24.0)
ER at 180°/s (%)	87.5 (19.3)	81.4 (21.3)	88.9 (10.0)	87.9 (11.1)
Abduction/adduction				
PT at 60°/s (%)	83.4 (8.6)	82.1 (11.3)	77.2 (11.3)	85.4 (13.2)
PT at 180°/s (%)	78.6 (14.5)	76.6 (11.6)	68.1 (11.6)	73.4 (13.0)

Values are mean (SD).

What is already known on this topic

- There are few papers on isokinetic testing in tennis players in the literature
- Isokinetic testing is the method usually used to evaluate muscle strength

What this study adds

- This is the first study to report isokinetic evaluation of horizontal shoulder abduction and adduction in elite level junior tennis players

those for the 11–14 year age group for all variables (PT, PT/BW, TW) except ER, HAB/HAD ratio, and TW/BW for abduction. This may be partly due to the methodology used in our study, as we tested at the maximum speed of 180°/s because of the difficulty of stabilising the trunk at high speeds.

The study also sought to determine whether players who had spent more time playing tennis became stronger in the movements most commonly used in the sport. We found that, although absolute PT and TW were significantly higher for those who had been playing tennis for over six years, the relative values were no higher than for those who had been playing for less than six years. We believe that playing tennis for a long period causes relative adaptations between increased muscular mass and the strength from increased body weight, thus maintaining a balanced ratio between torque and weight.

We know that isokinetic data have limitations. The position of the subject on the testing table is not physiological and eliminates gravity (although this is supposedly corrected for). This removes the role of the trunk in stabilising and generating force and eliminates contributions from the kinetic chain. This is a limitation of all isokinetic evaluations, and future studies will have to address this point.

Our study also had no control groups of non-players or athletes from other sports. Despite the unquestionable importance of a control group, in isokinetic testing the non-dominant side is usually used as a reference to establish differences in strength between the two sides. We also included tennis players who had no injuries in either shoulder.

The main goal of the paper was to establish a descriptive dataset for future studies, in which we will include athletes from other sports as well as normal non-athletic subjects.

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The subject has given permission for publication of the figures.

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COMMENTARY

This paper eloquently defines the muscular strength profile of the horizontal abductors and adductors of the elite tennis player. These muscles used extensively in the dominant arm, like other groups previously tested, show sport specific adaptations in the elite junior tennis player. The results of this paper can be applied to both injury prevention and evaluation of performance enhancement for the elite tennis player. This paper adds to the existing descriptive profile of upper extremity muscular strength in this population.

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