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Upper and Lower Body Strength Asymmetries and Shoulder Rotation Strength Ratio in Youth Tennis Players Using Isokinetic Testing

Koulla Parpa and Marcos Michaelides

School of Sciences, University of Central Lancashire (Cyprus Campus), Larnaca, Pyla, 7080, Cyprus

Abstract: Background: This study examined upper and lower body (interlimb) strength asymmetries and shoulder rotation strength ratios in youth tennis players using isokinetic testing. Methods: Seventeen players (male = 10, age: 15.60 ± 1.65 years; female = 7, age: 15.57 ± 1.51 years) from the same tennis academy volunteered to participate in the study. Handgrip strength, internal and external rotators' torque and the torque produced by the quadriceps and hamstring muscles were evaluated. Results: Significant upper limb asymmetries were indicated in strength between the dominant and non-dominant arms in several areas: handgrip strength (p = 0.01), internal and external rotators' torque at 60 °/s (p = 0.01) and 180 °/s (p = 0.01) and the ratios of external and internal rotation (ER:IR ratios) (p = 0.01). Lower body torque assessment did not reveal any asymmetries. Conclusion: Our findings highlight that significant interlimb asymmetries are evident in youth tennis players' upper body but not the lower body. These upper limb asymmetries develop early, making it essential for coaches and athletes to recognize them for injury prevention and performance enhancement. A focus should be placed on adding exercises that strengthen the external rotators of the dominant arm as well as the internal and external rotators of the non-dominant arm.

Key words: Interlimb asymmetries, internal rotators, external rotators, unilateral sports.

1. Introduction

Interlimb strength asymmetries in the upper or lower limbs refer to strength deficits between the limbs (e.g., between dominant and non-dominant sides) [1, 2], while muscular imbalances refer to the strength differences between the agonist and antagonist muscle groups [3]. Numerous investigators have characterized interlimb strength asymmetries as a potential factor that could lead to reduced performance [4] and increased susceptibility to injuries [5]. Research suggests that interlimb strength asymmetries over 10% may be detrimental to jumping, kicking, change of direction and cycling performance [6]. Additionally, an imbalance in the strength of the IR (internal rotators) and ER (external rotators) of the shoulder joint has been considered a potential factor contributing to shoulder dysfunction [7]. The ER:IR ratio, which represents the balance between agonist and antagonist muscle strength, has been utilized to identify potential risk factors for shoulder pathology [8], with the reported value of the ER:IR ratio being approximately 0.66 in healthy individuals [9].

Evidence suggests that engaging in sports that involve unilateral movements and asymmetric kinetic patterns can cause prolonged one-sided strain, which may lead to a range of interlimb strength asymmetries over time [10]. Studies have already reported the prevalence of lower limb strength asymmetries in various sports modalities [10], such as soccer, futsal, volleyball, and basketball, and identified possible discrepancies between youth and adult male and female athletes [10]. Furthermore, asymmetries in the lower limbs have been examined across athletes from various levels or divisions, focusing on the assessment of peak

Correspondence: Koulla Parpa, Ph.D., FHEA, FECSS, Assistant Professor-Course Leader for MSc in Sports and Exercise Science, research fields: exercise science.

isokinetic torques of the knee joint [11]. Additionally, imbalances between IR and ER of the shoulder joints have been reported in elite volleyball players, with authors suggesting that rotator muscle strength imbalances could play an important role in shoulder injuries [12].

Tennis is a highly unilateral sport that demands high levels of strength, cardiovascular endurance, speed, and power to perform high stroke velocities, in addition to technical and tactical skills [13, 14]. These sport-specific movements have been suggested to lead to upper and lower limb strength asymmetries [15, 16]. Researchers who examined the functional asymmetries of upper and lower extremities in internationally versus nationally ranked female tennis players utilizing field-based testing [16] demonstrated significant whole-body asymmetries. Concurrently, significant morphological and functional asymmetries have been reported in terms of muscle mass and strength of the dominant hand in Division I collegiate male and female tennis players [17]. Similarly, significant differences between the dominant and non-dominant upper extremity muscle volumes (deltoid, triceps brachii, arm flexors and forearm superficial flexor) have been indicated in professional male tennis players [18]. Additionally, significantly greater strength of the IR and lower ER:IR ratio have been linked to an increased risk of injuries in tennis players [19-21], with the recommended ER:IR ratio for non-injured tennis players being between 61%-76% [20].

To the best of our knowledge, most of the studies that assessed lower body asymmetries in junior tennis players used field-based physical performance tests [22] or isokinetic testing at much faster speeds [23], which might not have indicated the maximum torque production. Although exploring side-to-side differences in performance through field-based testing is crucial, utilizing isolated laboratory strength tests can also offer valuable insights to coaches and athletes. Also, 60 °/s for the isokinetic testing of the knee joint has been indicated to be a reliable assessment for maximum strength, whereas 180 °/s may require more familiarization when testing young athletes [24]. Additionally, investigating the IR strength and ER:IR ratio of the shoulder joint in youth players could be essential, given their association with injuries [19-21]. Therefore, this observational study aimed to examine upper and lower body (interlimb) strength asymmetries and shoulder rotation strength ratio in male and female youth tennis players using isokinetic testing. It was hypothesized that significant differences in torque production would be observed between the dominant (D) and non-dominant (ND) limbs of both the upper and lower body. Furthermore, it was hypothesized that ER:IR ratios of the dominant side would be significantly different than those of the non-dominant side.

2. Materials and Methods

2.1 Participants

A convenient sample of seventeen youth tennis players (male = 10, age: 15.60 ± 1.65 years; female =7, age: 15.57 ± 1.51 years) from the same tennis academy volunteered to participate in the study. Players engaged in four training sessions per week of approximately 90 min per session, and they had at least three years of tennis experience (3.50 ± 0.99). Exclusion criteria included injuries within the last six months prior to the data collection. Parents and legal guardians were informed about the procedures and signed an informed consent. The study was conducted in accordance with the Declaration of Helsinki and was approved by the National Committee of Bioethics. Anthropometric and body composition parameters are displayed in Table 1.

2.2 Procedures

Initially, the players' anthropometric and body composition parameters were assessed. Stature was evaluated with the use of a wall stadiometer (Charter HM200P stadiometer, Greece). Body composition was assessed with the bioelectrical impedance analyzer (BC418MA, Tanita). They were instructed to follow

Table 1 Anthropometric, body composition and years of tennis experience (mean ± SD) of youth male and female tennis players.

Variables	Entire group (n = 17)	Males (n = 10)	Females (n = 7)
Age (year)	15.59 ± 1.54	15.60 ± 1.65	15.57 ± 1.51
Height (cm)	172.00 ± 10.05	176.25 ± 10.05	165.93 ± 6.69*
Weight (kg)	63.24 ± 7.99	64.63 ± 8.99	61.26 ± 6.41
BMI (kg/m^2)	21.27 ± 1.48	20.68 ± 1.23	22.10 ± 1.49*
Body fat (%)	16.54 ± 5.68	12.31 ± 2.48	22.57 ± 2.13*
Years of tennis experience (year)	3.50 ± 0.99	3.60 ± 0.84	3.71 ± 0.76

* $p < 0.05$, denotes significant differences between male and female tennis players, BMI: Body mass index.

the standard guidelines before the bioelectrical impedance assessment [25]. Following that, the players performed an upper-body dynamic warm-up based on their routine before regular training sessions. Once the warm-up was complete, they performed a handgrip assessment with the use of a handgrip dynamometer (Takei Scientific Instruments, Tokyo, Japan) to assess the maximal isometric strength of the forearm and hand muscles. Three attempts were performed, and the best attempt was retained for further analysis, following the recommended procedures [26]. Thereafter, they were prepared for the evaluation of the internal and external rotators with the use of isokinetic testing. The assessment of isokinetic torque in the lower body was conducted following the evaluation of the upper body.

2.2.1 Isokinetic Assessment of Internal and External Rotators

The shoulders' internal and external rotators' peak torque was tested in a standing position following the manufacturer's guidelines on a HUMAC norm isokinetic device (CSMI, Stoughton, MA, USA). The position was obtained by tilting the dynamometer approximately 70° from the horizontal position. The wrist/shoulder adapter was inserted into the long end of the input arm, and the handgrip was secured at shoulder position 110. The players were instructed to stand on the monorail deck with their hips locked and one leg slightly forward while their non-testing hand rested on the thigh. The dynamometer was adjusted so that the arm was flexed 90° at the elbow, and the shoulder was slightly abducted. The axis of rotation was adjusted, and the forearm was stabilized in the elbow stabilizer pad. The range of motion of internal and external rotation was from 80° to 60°. This was adjusted in case the players did not fit into the normal range of motion. They performed five warm-up repetitions. The non-dominant arm was tested first. They performed five repetitions at 60°/s and 15 repetitions at 180°/s for the evaluation of peak torque and strength deficits. Each test was separated by 60 s of rest, and the same expert examiner was responsible for the examination and set-up of the testing.

2.2.2 Isokinetic Assessment of Knee Flexors and Extensors

Before the testing, the players performed a 5-min warm-up on a mechanically braked cycle ergometer. Peak torque for knee flexors and extensors was identified at 60°/s with the use of a HUMAC norm isokinetic device according to the methodology described by previous investigators [27]. Once they were appropriately positioned on the isokinetic device, they performed five repetitions for familiarization purposes. The testing involved three maximal concentric flexion and extension repetitions at 60°/s. The maximal torque out of the three was retained for further analysis. The same expert examiner was responsible for the set-up and testing.

2.3 Statistical Analysis

Statistical analysis was performed in IBM SPSS Statistics (version 28.0) for Windows (SPSS Inc., Chicago, IL, USA). Parameters are presented as means and standard deviations after the normality assumption was confirmed. The normality assumption was tested using the Shapiro-Wilk test. Even though it was not the primary purpose of the study, male and female results were compared using an independent sample *t*-test. In addition, a paired sample *t*-test was utilized to compare dominant versus non-dominant limbs. Cohen's *d* was calculated to identify the ES (effect size) and present the magnitude of the reported effects. The desired cut-off for interlimb asymmetries was set at 15% [28], and the number of participants who presented asymmetries larger than the cut-off was presented. ES was considered as small (0.2-0.4), medium (0.5-0.7) and large (0.8-1.4) [29]. The level of significance was set at 0.05.

3. Results

The results of the anthropometric evaluation, body composition and years of tennis experience are presented in Table 1. Upper body strength characteristics (normalized to body weight) are presented in Table 2. Results demonstrated significant differences between males and females for dominant handgrip strength [$t(15)$ = 4.88, p = 0.01], non-dominant handgrip strength [$t(15)$ = 3.96, p = 0.01], dominant arm internal rotators' torque at 60 °/s [$t(15)$ = 1.59, p = 0.01], non-dominant arm internal rotators torque at 60 °/s [$t(15)$ = 2.30, p = 0.01], dominant arm external rotators at 60 °/s [$t(15)$ = 3.47, p = 0.01] and non-dominant arm external rotators at 60 °/s [$t(15)$ = 3.02, p = 0.01]. No significant differences between male and female players were indicated at 180 °/s for both internal and external rotators of the dominant and non-dominant arms or the ER:IR ratios (Table 2).

Regarding significant upper interlimb asymmetries in strength between the dominant and non-dominant arms, tennis players indicated significant differences in handgrip strength [$t(15)$ = 14.39, p = 0.01, d = 1.86], internal rotators torque at 60 °/s [$t(15)$ = 12.18, p = 0.01, d = 1.02], external rotators torque at 60 °/s [$t(15)$ = 7.06, p = 0.01, d = 0.71], and internal rotators' torque at 180 °/s [$t(15)$ = 7.85, p = 0.01, d = 0.69], external rotators torque at 180 °/s [$t(15)$ = 10.03, p = 0.01, d = 0.56], and ER:IR ratios [$t(15)$ = -3.85, p = 0.01, d = 0.85]. The same upper body strength asymmetries were evident when the players were analyzed based on gender (Table 3).

Lower body torque (relative) values are presented in Table 4. Relative to body weight values indicated significant differences between male and female players at 60 and 300 °/s without any differences in the hamstring and quadriceps deficits, which were considered normal.

Table 2 Upper body strength characteristics (means ± SD, normalized to body weight) of male and female youth tennis players. Torque was measured at 60 and 180 °/s.

Variables	Males (n = 10)	Females (n = 7)	Cohen's d
Handgrip dominant hand (kg/BMI)	0.64 ± 0.05	0.52 ± 0.03*	2.9
Handgrip non-dominant (kg/BMI)	0.50 ± 0.08	0.37 ± 0.03*	2.15
Internal rotators (60°/s) dominant arm (Nm/kg)	0.78 ± 0.15	0.50 ± 0.17*	1.75
Internal rotations (60°/s) non-dominant arm (Nm/kg)	0.57 ± 0.11	0.36 ± 0.15*	1.60
External rotators (60°/s) dominant arm (Nm/kg)	0.49 ± 0.11	0.29 ± 0.12*	1.74
External rotations (60°/s) non-dominant arm (Nm/kg)	0.38 ± 0.09	0.24 ± 0.09*	1.55
ER:IR ratio dominant arm (%)	62.39 ± 6.45	58.07 ± 7.68	
ER:IR non-dominant arm (%)	66.07 ± 8.10	69.32 ± 4.83	
Internal rotators (180°/s) dominant arm (Nm/kg)	0.55 ± 0.09	0.43 ± 0.22	
Internal rotators (180°/s) non-dominant arm (Nm/kg)	0.43 ± 0.06	0.36 ± 0.19	
External rotators (180°/s) dominant arm (Nm/kg)	0.38 ± 0.10	0.27 ± 0.15	
External rotators (180°/s) non-dominant arm (Nm/kg)	0.32 ± 0.08	0.21 ± 0.14	

* $p < 0.05$ denotes significant differences between male and female values; ER: External rotators; IR: Internal rotators.

Table 3 Interlimb asymmetries [dominant (D) versus non-dominant (ND) arm relative to body weight values] and shoulder rotation strength ratios for the whole group and youth male and female tennis players.

Variables	Mean difference ± SD	SE	95% CI	Cohen's *d*
Whole group (*n* = 17)				
Handgrip D, ND	0.15 ± 0.04*	0.01	0.13-0.17	1.87
Internal rotators (60°/s), D, ND	0.18 ± 0.06*	0.02	0.15-0.22	1.02
External rotators (60°/s), D, ND	0.09 ± 0.05*	0.01	0.06-0.11	0.68
Ratio ER:IR (%), D, ND at 60°/s	-9.80 ± 7.23*	1.75	-10.5-3.08	0.97
Internal rotators (180°/s), D, ND	0.99 ± 0.05*	0.01	0.07-1.12	0.69
External rotators (180°/s), D, ND	0.06 ± 0.03*	0.01	0.05-0.08	0.56
Males (*n* = 10)				
Handgrip D, ND	0.14 ± 0.05*	0.01	0.11-0.17	2.02
Internal rotators (60°/s), D, ND	0.21 ± 0.06*	0.02	0.17-0.26	1.60
External rotators (60°/s), D, ND	0.11 ± 0.04*	0.01	0.08-0.14	1.09
Ratio ER:IR (%) at 60°/s	-3.68 ± 4.39*	1.36	-6.76-0.61	0.50
Internal rotators (180°/s), D, ND	0.12 ± 0.05*	0.02	0.08-0.15	1.57
External rotators (180°/s), D, ND	0.06 ± 0.03*	0.01	0.04-0.08	0.67
Females (*n* = 7)				
Handgrip D, ND	0.16 ± 0.04*	0.01	0.12-0.19	4.82
Internal rotators (60°/s), D, ND	0.14 ± 0.04*	0.01	0.11-0.18	0.87
External rotators (60°/s), D, ND	0.05 ± 0.04*	0.01	0.02-0.08	0.48
Ratio ER:IR (%) at 60°/s	11.25 ± 8.51*	3.21	-19.12-3.38	1.75
Internal rotators (180°/s), D, ND	0.07 ± 0.05*	0.02	0.03-0.11	0.34
External rotators (180°/s), D, ND	0.06 ± 0.02*	0.01	0.04-0.08	0.41

* $p < 0.05$ denotes significant differences between dominant and non-dominant arms, BMI: Body mass index.

Table 4 Lower body strength characteristics (means ±SD, normalized to body weight) of male and female youth tennis players. Torque is measured at 60 and 300 °/s.

Variables	Males (*n* = 10)	Females (*n* = 7)	Cohen's *d*
Quadriceps torque dominant leg (60°/s) (Nm/kg)	2.86 ± 0.58	2.29 ± 0.40*	1.14
Quadriceps torque non-dominant leg (60°/s) (Nm/kg)	2.96 ± 0.64	2.23 ± 0.37*	1.39
Hamstring torque dominant leg (60°/s) (Nm/kg)	2.00 ± 0.37	1.38 ± 0.21*	2.06
Hamstring torque non-dominant leg (60°/s) (Nm/kg)	2.01 ± 0.41	1.41 ± 0.21*	1.84
Quadriceps torque dominant leg (300°/s) (Nm/kg)	1.48 ± 0.34	1.05 ± 0.15*	1.64
Quadriceps torque non-dominant leg (300°/s) (Nm/kg)	1.53 ± 0.33	1.02 ± 0.14*	2.01
Hamstring torque dominant leg (300°/s) (Nm/kg)	1.23 ± 0.19	0.87 ± 0.13*	2.21
Hamstring torque non-dominant leg (300°/s) (Nm/kg)	1.25 ± 0.19	0.92 ± 0.14*	1.98

* $p < 0.05$ denotes significant differences between male and female relative torque values.

Furthermore, no significant lower body strength interlimb asymmetries were indicated for the players when analyzed as a group or by gender. Table 5 indicates the strength asymmetries (%) between the dominant and non-dominant sides for both the upper and lower body.

Regarding handgrip asymmetries, 70% of the male (7 out of 10) and 85.7% (6 out of 7) of the female players presented asymmetries that exceeded the desired cut-off value of 15%. Regarding the asymmetries of internal rotators at 60 °/s, 90% of the male (9 out of 10) and 100% of the female players presented asymmetries that exceeded the desired cut-off. In addition, 70% of the male (7 out of 10) and 57% of the female (4 out of 7) players presented external rotators' asymmetries at 60 °/s that exceeded the desired cut-off value.

Table 5 Upper and lower body strength asymmetries between the dominant and non-dominant sides (presented as %).

Variables	Entire group (*n* = 17)	Males (*n* = 10)	Females (*n* = 7)
Handgrip strength D-ND	25.45%*	22.44%*	29.74%*
Internal rotators (60°/s) D-ND	28.22%*	27.14%*	29.77%*
External rotators (60°/s) D-ND	19.95%*	22.90%*	15.73%*
Internal rotators (180°/s) D-ND	19.38%*	20.91%*	17.18%*
External rotators (180°/s) D-ND	19.60%*	16.73%*	23.71%*
Quadriceps (60°/s) D-ND	5.59%	6.40%	4.43%
Hamstring (60°/s) D-ND	5.18%	5.50%	4.71%
Quadriceps (300°/s) D-ND	5.82%	5.80%	5.86%
Hamstring (300°/s) D-ND	6.18%	6.60%	5.57%

* denotes significant asymmetry between dominant and non-dominant sides; D: Dominant side, ND: Non-dominant side.

Regarding the isokinetic assessment at higher angular velocities, 70% of the male (7 out of 10) and 42.8% of the female (3 out of 7) players presented asymmetries for the internal rotators over the cut-off value. In comparison, 30% of the male (3 out of 10) and 57% of the female (4 out of 7) players presented asymmetries over the cut-off value for the external rotators.

4. Discussion

This observational study aimed to examine upper and lower body (interlimb) strength asymmetries in male and female youth tennis players using isokinetic testing. Our results highlight that significant interlimb asymmetries are evident in the upper body but not the lower body of youth tennis players (Table 5). Significant asymmetries between the dominant and non-dominant sides were indicated in handgrip strength, internal and external rotators' torque at 60 °/s, internal and external rotators' torque at 180 °/s, and ER:IR ratios. No significant lower body strength interlimb asymmetries were indicated for the players when analyzed as a group or by gender.

Regarding the upper extremity, the participants performed significantly better on handgrip strength and internal rotators' torque with the dominant upper extremity compared to the non-dominant side. The magnitudes of handgrip strength asymmetries in our study significantly exceeded those reported by previous investigators. Our results indicated a 25.5% asymmetry in handgrip strength between the dominant and non-dominant hands, with the female participants exhibiting even larger asymmetries (29.74%). In contrast, a study on internationally ranked and nationally ranked female tennis players aged between 17 and 27 reported handgrip strength asymmetries between 10.8% and 15.2% [16]. Comparable results were demonstrated in a study by Ducher and Colleagues [30], which reported a 13.3% asymmetry in handgrip strength among male and female adult tennis players with an average of 14.3 years of playing experience. Greater asymmetries (17.3%) in handgrip strength were reported in younger male tennis players (mean age 13.6 years) who had at least four years of playing experience at a competitive level [31]. These results are not surprising considering the unilateral loading on the dominant hand during tennis. It is, however, essential to note that based on our findings, the asymmetry in handgrip strength develops early, as evidenced by our participants, who had an average of 3.50 years of tennis experience.

Adaptive strength changes in the dominant arm were also evident based on the isokinetic assessment of internal and external rotators. Our findings revealed significant asymmetries in internal rotators' torque (28.22%) when the dominant side was compared to the non-dominant side at 60 °/s. Similar asymmetries were confirmed by previous investigators who reported 21.4% asymmetries in internal rotators when the tennis players were tested at 60 °/s [32]. Concurrently, similar asymmetries (21.9%) were noted when the tennis players were tested at faster speeds (300 °/s) [32], which is also in agreement with our findings that indicated an asymmetry of internal rotators of 19.38% when they were tested at 180 °/s. It should be noted that asymmetries were also reported for the external rotators' torque between dominant and don-dominant arms at both speeds. While the asymmetry in the internal rotators was anticipated, given their significant role during the serving motion, it appears that the external rotators develop a certain degree of asymmetry. Despite their primary role in decelerating the arm during the serve, they are still engaged in a repetitive, unilateral manner, which might explain these results. This finding is not in agreement with a previous investigation that reported no significant asymmetries on the external rotators at 60 °/s (5.17%) or 300 °/s (12%) [32].

Regarding ER:IR ratios, our results indicated ratios of 62.39% and 58.07% for the dominant hand for males and females, respectively. Concurrently, the ER:IR ratios for the non-dominant arm were 66.07% and 69.32% for males and females, respectively. Research reported ER:IR ratios of approximately 66% and 61-76% in healthy individuals [12] and non-injured tennis players [20], respectively. Based on the findings from previous investigators, our results for the dominant side are considered marginally lower than normal. These findings are of great importance, considering the increased risk of injuries in tennis players [19-21], which is associated with lower ER:IR ratios.

In contrast to the findings in the upper extremity, no significant differences were indicated between the dominant and non-dominant lower limbs for the peak torque of the quadriceps and hamstring muscles. This finding aligns with previous investigations that also utilized isokinetic testing to assess lower body torque in junior tennis players [23, 33] and elite adult tennis players [34]. Therefore, in contrast to the interlimb asymmetries reported in field testing studies [16, 22], no interlimb asymmetries are observed when tennis players are assessed with the isokinetic device. Of note is that the previous investigators [23, 33] who used isokinetic testing to evaluate the torque of the quadriceps and hamstring muscles tested the young athletes at speeds between 180 and 300 °/s while our study assessed the youth athletes at 60 and 300 °/s. Based on these findings, lower limb asymmetries are not expected during the isokinetic testing of tennis players. Thus, it can be suggested the isokinetic evaluation may be utilized for performance enhancement or rehabilitation purposes rather than the evaluation of interlimb asymmetries in the lower body of youth tennis players.

5. Conclusion

Our results highlight that interlimb asymmetries are evident in the upper body but not the lower body of youth tennis players assessed through isokinetic testing. These upper limb asymmetries develop early, and it is essential for coaches and athletes to recognize them for injury prevention and performance enhancement. A focus should be placed on adding exercises that strengthen the external rotators of the dominant arm as well as the internal and external rotators of the non-dominant hand.

Isokinetic assessment at slow speeds (60 °/s) does not indicate interlimb asymmetries in the lower body. Therefore, the isokinetic device may be used for rehabilitation purposes or performance enhancement. Conversely, field testing may serve as a more appropriate method for the identification of lower body interlimb asymmetries in youth tennis players.

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