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Article

Relationship between Interlimb Asymmetries and Performance Variables in Adolescent Tennis Players

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Abstract: Tennis is an individual sport characterised by high intensity action, including sprints and changes of direction (COD). There is a gap in the knowledge of limb asymmetries in adolescent tennis players and their association with performance. This study aimed to examine the relationship between asymmetry in vertical and horizontal jump tests (CMJ and HJ) and COD with lower limb performance variables in adolescent tennis players. Forty-five adolescent tennis players (age: 13.81 ± 1.08 years; height: 167.64 ± 9.9 cm; body mass: 57.48 ± 10.94 kg; body mass index: 20.27 ± 2.18 kg/m²) performed the CMJ test (unilateral and bilateral), horizontal jumps (unilateral and bilateral), 25 m sprint and 180° COD test. The single-leg countermovement jump showed the greatest asymmetries among the different tests ($6.62 \pm 9.35\%$). Significant negative relationships were found between CMJ asymmetry and COD asymmetry with unilateral horizontal jump variables ($r = -0.30$ to -0.53). In addition, CMJ asymmetry showed significant relationships with CMJR ($r=0.49$) and COD180R ($r=0.29$), whereas COD asymmetry showed a significant relationship with COD180L ($r=0.40$). On the other hand, HJ asymmetry showed no significant relationships with any variable. The main findings of this study indicate that greater imbalances in the CMJ and COD tests are associated with a reduced capacity to perform unilateral horizontal jumps. These results suggest the need to incorporate training protocols that reduce interlimb asymmetries in growing athletes to improve their performance.

Keywords: adolescent; tennis; men; multidirectional speed; performance

1. Introduction

Tennis is a sport in which individuals or pairs compete to hit the ball over the net so that the opponent cannot return the shot [1]. The court measures 11.90–10.97 metres [2] and points can last from 4 to 10 s, with breaks of 10 to 20 s between points [1]. This sport involves high-intensity actions such as sprints (between 8m and 15m), accelerations, decelerations, changes of direction (3-4 on average), and jumps [1-5]. It is very unlikely that these actions will occur the same number of times on each limb, making it highly likely that neuromuscular asymmetries will develop over the course of the season (5).

Limb asymmetry has been a common line of research in recent years [3,6]. This term refers to the differences between one limb and the other [7,8]. These asymmetries indicate strength deficits between the two limbs [3]. For example, the ratio of hamstrings to quadriceps (H:Q) is between 50% and 80%. In addition, asymmetry greater than 10-15% is associated with a higher risk of injury [3,9,10]. In tennis, there is a paucity of literature on asymmetry [2,11]. Therefore, it is important for sports coaches to understand the importance of limb asymmetry to improve the performance of their athletes [10].

Limb asymmetries and their association with injury risk have been the subject of increasing research in recent years [9,12,13]. The lower limbs are most commonly injured (39-59%), followed by

the upper limbs (20-40%) and the trunk (11-30%) [14,15]. Asymmetries between 10% and 15% are often associated with a higher risk of injury and reduced performance [6,16]. If these tests reveal an asymmetry of >10%, this indicates a fourfold increase in the risk of lower limb injury. Similarly, an asymmetry of more than 4 cm on the Y-balance test (YBT) would indicate the same increased risk of injury [17]. Therefore, strength training programmes should include both bilateral and unilateral exercises to reduce these asymmetries [7].

Finally, various tests are used to detect asymmetries in athletes using jump tests, such as the single-leg vertical and horizontal jump, as this is a reliable and efficient method (6, 13). Other tests used include measuring the isokinetic peak for knee flexion and extension between the dominant and non-dominant limbs [9]. Once the differences between the limbs have been identified, studies have shown that the implementation of a neuromuscular training programme can reduce these asymmetries [2].

Furthermore, the relationship between asymmetries and performance has increased publications on this topic recently. In general, strength asymmetry is negatively correlated with jump performance, speed, and change of direction speed [6]. Other studies have shown that athletes with better symmetry data are faster than asymmetric athletes in team sports [7]. Another study suggests that greater lower limb asymmetry in jumping tests is associated with a reduction in 5, 10, and 20-m sprints in youth soccer players [5]. A final study suggests that asymmetries in the one-legged vertical jump test are associated with slower 5-m sprint speeds in youth soccer players [18]. Performance and asymmetries have been analysed in many team sports, but not in individual sports; therefore, more studies are needed before conclusions can be drawn.

Therefore, the main objective of this study was to examine the relationship between asymmetry in vertical and horizontal jump tests (CMJ and HJ) and change of direction (COD) with lower limb performance variables in adolescent tennis players.

2. Materials and Methods

2.1. Participants

Forty-five adolescent male tennis players (age: 13.81 ± 1.08 years; height: 167.64 ± 9.9 cm; body mass: 57.48 ± 10.94 kg; body mass index: 20.27 ± 2.18 kg/m²) consented to participate in the study. An initial power analysis was conducted to determine the necessary number of participants using the G*Power software (version 3.1.9.3, based in Düsseldorf, Germany). Considering the study design, which investigates variances within a single group and accounts for an effect size of 0.5, a significance level (alpha) of 0.05, and a desired power of 95%, it was established that 38 subjects would be required. Nonetheless, the study included 45 participants, giving a statistical power of 97%.

All tennis players belonged to two different tennis academies and followed a systematically structured training programme, consistent in both volume and methodology. This regimen included four 90-minute technical-tactical training sessions per week and two physical training sessions per week. In addition, the players were injury-free during the data collection period. Written informed consent was obtained from the parents or guardians of all participants. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (2013) and received approval from the University Ethics Committee (approval no. 46/2/22-23).

2.2. Procedures

Physical performance assessments were conducted on the same day at the players' usual training times (18:00) in favourable weather conditions. Players were instructed to avoid strenuous physical activity for 48 h before the assessment tests. All players were familiar with the tests to be conducted, as these are tests that are included in the Academy's programme throughout the season. Players tested on a hard tennis surface using specific tennis shoes. A Rise, Activate, Mobilise and Potentiate (RAMP) system warm-up protocol was performed before testing [19]. After the warm-up, three practise runs were completed for each test. A 3-min rest period was allowed between the last practise run and the start of the first test. The order in which the tests were performed was as follows:

unilateral vertical jumps, bilateral vertical jumps, unilateral horizontal jumps, bilateral horizontal jumps, 180° change of direction, and 25 m sprint. Unilateral tests were always started with the right leg and finished with the left leg. There was a 3-min break between races and allow players to hydrate.

2.2.1. Unilateral and bilateral Countermovement Jump Test

Lower body performance in the vertical plane was measured using the countermovement jump test. Optogait systems (Microgate, Bolzano, Italy) were used as an evaluation instrument to measure performance (jump height) and are described elsewhere [20]. The evaluation protocol for each test (bilateral, right and left) was performed twice, with 45 s of recovery between each attempt. The best score in each test was recorded for subsequent analysis using the following variables: countermovement jump right (CMJR), countermovement jump left (CMJL), and bilateral countermovement jump (CMJ).

2.2.2. Unilateral and bilateral Horizontal Jump Test

Lower body performance in the horizontal plane was measured using the horizontal jump test of tennis players. Standard 30 m tape measure 30 m (M13; Stanley, New Britain, EEUU) was used as an evaluation instrument to measure performance (distance) and is described elsewhere [20]. The evaluation protocol for each test (bilateral, right and left) was performed twice, with 45 s of recovery between repetitions. The best score in each test was recorded for subsequent analysis using the following variables: horizontal jump right (HJR), horizontal jump left (HJL) and bilateral horizontal jump (HJ).

2.2.3. 25m Sprint Test

The 25 m sprint tests were conducted to assess the top speed of the tennis players. The timing was performed using double-beam photoelectric cells (Witty, Microgate, Bolzano, Italy). The timing gates were placed 1.5 m apart and at a height of 0.75 m. Each tennis player positioned himself behind the starting line, which was 0.5 m before the first marker, and started the sprint at his own discretion without any external signals. The total sprint distance was 25 m. Two repetitions of this test were performed, with a 2-min recovery between each attempt. The fastest time of the two sprints was selected for subsequent statistical analysis.

2.2.4. 180° COD Test

The change of direction performance was performed using a 10-m sprint with a COD of 180°. Photoelectric cells (Witty, Microgate, Bolzano, Italy) were used to measure the performance (i.e. time) and the test is described elsewhere [20]. The tennis players performed four COD tests, two with the right leg and two with the left leg, with a 2-min recovery between repetitions. The shortest time with each leg was recorded for statistical analysis with the following variables: 10-m sprint with one change of direction to the right (COD180R) and 10-m sprint with one change of direction to the left (COD180L).

2.3. Statistical Analyses

SPSS statistical software (Version 28.0; SPSS Inc, Chicago, IL, USA) was used for statistical analysis. The Shapiro-Wilk test was performed to assess normality for all variables

First, a one-way repeated measures ANOVA was performed to detect any systematic bias between the means of skewness in the performance variables. Asymmetries between the lower limbs were expressed as percentages (%) using the following equation [21]:

$$100/\text{Max value (right and left)} * \text{Min value (right and left)} * -1 + 100$$

Pearson's correlation test was used to determine correlations between limb asymmetries (%) and physical performance. A value 0.05 was considered statistically significant. In addition, the kappa coefficient was used to measure the consistency of the direction of asymmetry between tests,

interpreted as follows: poor (≤ 0), slight (0.01-0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80), almost perfect (0.81-0.99) and perfect [22].

3. Results

Descriptive data on the physical performance and asymmetries of tennis players are presented in Table 1.

Table 1. Descriptive data for all physical performance tests.

Variable	Mean $\pm$ SD	Asymmetry (%)
CMJR (cm)	14.46 $\pm$ 3.31	6.62 $\pm$ 9.35
CMJL (cm)	14.82 $\pm$ 3.70	
HJR (cm)	153.42 $\pm$ 21.90	3.97 $\pm$ 4.18
HJL (cm)	153.53 $\pm$ 24.24	
COD180R (s)	2.85 $\pm$ 0.12	1.47 $\pm$ 2.07
COD180L (s)	2.86 $\pm$ 0.12	
CMJ (cm)	29.11 $\pm$ 5.05	
HJ (cm)	190.38 $\pm$ 24.44	
20 m (s)	3.41 $\pm$ 0.17	

CMJR and CMJL: unilateral countermovement jump with right and left legs; HJR and HJL: unilateral horizontal jump with right and left legs; COD180R and COD180L: 10-m shuttle sprint with one change of direction to right or left; CMJ: bilateral countermovement jump; HJ: bilateral horizontal; jump20 m: linear sprint of 20 m.

Table 2 presents Pearson’s correlations between interlimb asymmetry scores and performance tests. Significant correlations were observed between CMJ Asymmetry and the variables CMJR ($r=-0.49$), HJR ($r=-0.53$), HJL ($r=-0.52$), and CODR 180 ($r=0.29$). Moreover, significant correlations were identified between COD Asymmetry and the variables HJR ($r=-0.30$), HJL ($r=-0.38$), and COD 180L ($r=0.40$). Conversely, no significant relationships were found between HJ Asymmetry and the variables associated with jumping, speed, and COD.

Table 2. Correlations between jump and change of direction tests and asymmetry percentages.

Test	CMJ Asymmetry	HJ Asymmetry	COD Asymmetry
CMJR (cm)	-0.49**	-0.08	-0.15
CMJL (cm)	-0.17	0.03	-0.05
HJR (cm)	-0.53**	-0.28	-0.30*
HJL (cm)	-0.52**	-0.17	-0.38**
COD180R (s)	0.29*	0.24	0.25
COD180L (s)	0.27	0.12	0.40**
CMJ (cm)	-0.28	-0.06	-0.06
HJ (cm)	-0.22	0.07	0.00
20 m (s)	-0.25	-0.28	-0.16

CMJR and CMJL: unilateral countermovement jump with right and left legs; HJR and HJL: unilateral horizontal jump with right and left legs; COD180R and COD180L: 10-m shuttle sprint with one change of direction to right or left; CMJ: bilateral countermovement jump; HJ: bilateral horizontal; jump20 m: linear sprint of 20 m. * Correlation is significant at the 0.05 level (bilateral).** Correlation is significant at the 0.01 level (bilateral).

Table 3 shows the levels of agreement of the asymmetry scores as measured by the Kappa coefficient. The results indicate fair agreement between the CMJ test and the COD180 test (-0.15), and slight agreement between the CMJ and HJ tests (0.01) and between the HJ and COD180 tests (-0.06). Figure 1 illustrates the discrepancies between the limbs for CMJ, HJ, and COD, highlighting the variability in both the magnitude and direction of the asymmetry.

Table 3. Descriptive levels of agreement and Kappa coefficients for asymmetries between jumping, speed, and COD tests.

Test	Kappa Coefficient	Descriptor
CMJ-HJ	0.02	Slight
CMJ-COD180	-0.15	Fair
HJ-COD180	-0.06	Slight

CMJR and CMJL: unilateral countermovement jump with right and left legs; HJR and HJL: unilateral horizontal jump with right and left legs; COD180R and COD180L: 10-m shuttle sprint with one change of direction to right or left; CMJ: bilateral countermovement jump; HJ: bilateral horizontal; jump20 m: linear sprint of 20 m.

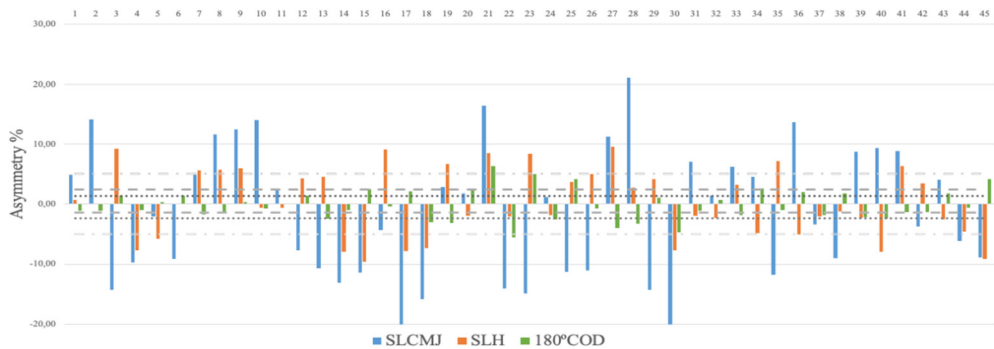


Figure 1. Individual asymmetry data for countermovement jump (CMJ), horizontal jump (HJ) and 180° change of direction (180°COD). Note: Values above 0 indicate right leg dominance and values below 0 indicate left leg dominance.

4. Discussion

The main findings of this study indicate significant correlations between the asymmetries observed in vertical jump and COD with single-leg horizontal jump (SLHJ) performance in highly trained adolescent tennis players. These correlations suggest that greater imbalances in the CMJ and COD tests are associated with a reduced ability to perform unilateral horizontal jumps, both with the right leg (HJR) and the left leg (HJL). In addition, asymmetries between jump and COD tests rarely favoured the same side, indicating the task-specific nature of the asymmetry.

The single-leg countermovement jump (SLCMJ) showed the greatest asymmetries among the different tests ($6.62 \pm 9.35\%$), as shown in previous studies with tennis players ($15.03 \pm 6.91\%$) [2]. CMJ asymmetry has a significant correlation with the right leg vertical jump ($r=-0.49$), according to the study by Bishop et al, who found the same significant correlation for the right leg ($r=-0.47$) and the left leg ($r=-0.53$) [23] . In addition, there was a significant correlation with unilateral horizontal jump in both the right and left legs. Regarding COD180, there is a significant correlation with the one performed using the right leg, which differs from the literature [6] . These results contradict another study of tennis players, which found a relationship between greater asymmetry and lower performance in COD [2]. However, in a handball article by Madruga et al. [24], there is a significant correlation with the 8 10 m repeated sprint test. These differences may be due to the specific demands and movement patterns of tennis, where asymmetries may result from unilateral training and the predominant use of one limb. For strength and conditioning coaches, these differences have important practical applications, such as the need to develop training programmes that minimise asymmetries and enhance the strength and agility of both legs, thereby improving performance and reducing the risk of injury [25].

The asymmetries in the single-leg horizontal jump ($3.97 \pm 4.18\%$) are similar to previous studies in tennis players ($4.14 \pm 3.72\%$) [2] and team sport athletes ($3.3 \pm 3.0\%$) [26]. In HJ asymmetry, there is no significant correlation with any variable, which is consistent with studies such as Bishop et al. [27]. However, Roso-Moliner et al [28] found a significant correlation with CMJ asymmetry, which is greater

in the left leg than in the right leg, as well as with HJ in the right leg of female football players. This may be because there are more vertical jumps in soccer than in tennis, highlighting the importance of future studies comparing different sports that work at different levels. In addition, strength and conditioning coaches should programme training in different planes and include both bilateral and unilateral training [29].

The asymmetries in COD ($1.47 \pm 2.07\%$) were smaller than the asymmetries of both jumps ($6.62 \pm 9.35\%$) and ($3.97 \pm 4.18\%$), showing similarity with the existing literature ($1.83 \pm 1.43\%$) [2] and ($2.39 \pm 1.64\%$) [6]. COD asymmetry in relation to HJ showed a significant correlation for both the right and left legs, with the left leg showing a stronger correlation. For COD180, the significant correlation with the left leg was positive, suggesting that players with greater asymmetry are more efficient at changing direction with this leg. However, in Madruga et al. [2] on tennis players, a significant correlation with the SLCMJ jump was observed. These observations suggest that asymmetries may differentially affect performance in different tests and skills, making it interesting to perform different tests based on specific actions of each sport analysed to understand the asymmetries of athletes [17,29].

Regarding the analysis of the Kappa results, it should be noted that in the present article, in the SLCMJ, there are 20 players with above 10% asymmetry. In both SLH and COD 180, all athletes had below 10% asymmetry. These data are very similar to the handball article by Madruga et al. [24], where 21 players have above 10% asymmetry in the SLCMJ. In another article on women's soccer by Roso-Moliner et al., only six players have >10% asymmetry in the SLCMJ and none in the SLHJ [28]. In all cases, the strength and conditioning coach should implement a training protocol to correct these asymmetries, thereby increasing athlete performance and reducing the risk of injury by keeping asymmetries below 10% [24,30].

Although these findings are valuable, the study has some limitations. First, only males were included in this study. Therefore, future studies should focus only on female athletes. Second, only non-professional athletes were included, not professional athletes. Future studies should consider these differences. Third, our study was conducted with 14-year-old athletes, and it would be interesting to conduct a study with athletes at different maturation stages.

5. Conclusions

This study analysed lower limb asymmetries in relation to performance variables in adolescent tennis players. In summary, asymmetries found in the CMJ and COD180 were related to lower performance in unilateral horizontal jump tests with both the right and left legs. However, HJ asymmetry was not significantly related to any performance variable. Due to the association of asymmetries with reduced physical performance, it is necessary to adapt training programmes to reduce asymmetries between limbs. The direction of asymmetries varies greatly in tennis players; therefore, it is necessary to individualise training for each subject to reduce asymmetries and improve their performance.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the University Ethics Committee (protocol code 46/2/22-23).

Informed Consent Statement: All participants provided informed consent. In addition, written permission to publish this document was acquired from both the subjects and their guardians.

Data Availability Statement: The data from this research can be made available by the corresponding author following a justified request. Due to privacy concerns, the data are not accessible to the public.

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