International vs. National Female Tennis Players: A Comparison of Upper and Lower Extremity Functional Asymmetries

Functional Asymmetries in Female Tennis Players

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Abstract

Background:

Asymmetries have been reported to negatively impact sport performance. This study examined the magnitude and direction of whole-body functional asymmetry in international versus national female tennis players.

Methods:

Ten internationally and twelve nationally ranked tennis players participated. Upper extremity functional asymmetries (or side-to-side performance differences) were evaluated using handgrip strength, seated shot-put throw and plate tapping. Lower extremity functional asymmetries were determined using the single leg countermovement jump, single leg forward hop test, 6 m single leg hop test, 505 changes of direction (time and deficit), and Y-balance test (anterior, posteromedial, posterolateral). ANOVAs were used to compare the dominant (overall best or fastest result of a specific test) versus non-dominant performance values (best or fastest result of the corresponding extremity) within the internationally versus nationally ranked players. Functional asymmetry magnitudes differences (expressed as a %) were examined using Mann-Whitney U tests. Kappa coefficients examined the consistency as to which extremity performed dominantly across tests.

Results:

Significant asymmetries for every upper and lower extremity test were found. The functional asymmetry magnitude was significantly (p=0.020) higher on the single leg forward hop test for the nationally (6.3%) versus internationally ranked players (2.9%). Kappa coefficients showed perfect levels of consistency regarding all upper extremity tests (k=1.00), indicating true limb dominance whereas more variance was found as to which lower extremity performed dominantly across tests (k range=-0.067-0.174).

Conclusions:

The included female tennis players displayed significant whole-body functional asymmetries. Poor consistency as to which lower extremity performed dominantly across tests warrants individual asymmetry monitoring.

Key Words: Women, imbalances, unilateral

Introduction

Functional (inter-limb) asymmetries refer to side-to-side differences in function or performance between corresponding upper or lower extremities as a consequence of executing repetitive movement patterns over time (1). Numerous studies have already examined and reported the prevalence of such functional asymmetries in a wide variety of sports such as swimming (2), rowing (3) and soccer (1) whilst examining a range of physical competencies, such as strength (4) and power (5). The magnitude of functional asymmetry can be quantified by calculating the percentage difference between corresponding upper or lower extremities' unilateral performances in physical tests. Functional asymmetries have been reported to negatively impact sports-specific performance. As such, previous research suggested that asymmetry magnitudes surpassing 10% could have a negative impact on change of direction, sprinting and jumping performance (6).

As a highly reactive unilateral sport, tennis is characterised by short high-intensity efforts generally lasting less than 10 seconds alternated by recovery bouts lasting between 20 and 25 seconds (7, 8). During these high-intensity efforts, tennis strokes are performed during which the player's preferred upper extremity (i.e., the upper extremity holding the racket) is subjected to a greater mechanical loading compared to the other upper extremity (9). Correspondingly, significant functional asymmetries (ranging from 12.5-25.0%) have been reported in terms of hand grip strength among recreational male and female adult tennis players (10-12). Similarly, significant side-to-side differences in performance at the upper extremity level have also been demonstrated regarding triceps strength (10%) among professional male tennis players (13).

However, playing tennis is also likely to impose an uneven mechanical loading on the lower extremities. It has been reported that both lower extremities are loaded differently due to their specific role in the kinetic chain when players are performing tennis strokes (14, 15). This side-to-side difference in mechanical loading could also contribute to the development of lower extremity functional asymmetries. For example, an essential component of playing tennis involves changes of direction (COD), with players performing on average 4 COD per point played (8). Due to the sport-specific demands of tennis, players tend to use their forehand side more than their backhand side. Subsequently, tennis players perform more COD on their forehand side, which could also lead to lower extremity functional asymmetries (8). To the best of our knowledge, only two studies have previously examined side-to-side differences in performance at the lower extremity level among tennis players. The first study reported functional asymmetries during forward hopping (9.0%), side hopping (10.8%) and lateral sprinting (7.2%) (16). The second study reported significant side-to-side differences between both lower extremities during single-leg vertical jumping (14.7%), a single-leg balance test (3.5%) and a COD speed test (2.1%) (17).

It should be noted, however, that both aforementioned studies were performed in youth tennis players of both sexes and that data concerning whole-body functional asymmetries (i.e., for at the upper and lower extremity level) is currently lacking in elite adult female tennis players. Since females respond differently to exercise compared to males, there is a need to specifically examine functional asymmetries in female tennis players (18). In addition, it could be argued that elite level tennis players are well suited to examine functional asymmetries since reaching an elite level requires a high training volume, which has been reported to be associated with the occurrence of asymmetry (19). Finally, elite level tennis players usually tend to start training at a relative young age, which could also contribute to the exacerbation of asymmetries (20).

In addition to the lack of research in female tennis players, it is unknown whether the magnitude of functional asymmetry differs according to players' performance level or ranking. It is also important to note that functional asymmetries are reported to be movement or task related. Accordingly, it is essential to examine side-to-side differences in performance using a comprehensive test battery as opposed to isolated testing (21). Therefore, the aim of this observational cross-sectional study is to examine and compare the magnitude of upper and lower extremity functional asymmetries in internationally versus nationally ranked female tennis players using a comprehensive field-based physical performance test battery.

Materials and Methods

Participants

The present study protocol was approved by the local university's medical ethics committee (B.U.N. 143201836107). All participants (as well as their legal representative if they were still minor) were informed of the benefits and risks of the study prior to signing an informed consent. To be eligible, participants had to be female, had to be free of injury at the time of data collection (i.e., between March 2019 and September 2020), and had to be either an internationally ranked player (i.e., having an International Tennis Federation (ITF) or a Women's Tennis Association (WTA) ranking) or a nationally ranked player (i.e., be in the top 200 of the Belgian Circuit, which is the highest division of Belgian tennis). As such, a total of 22 Belgian female tennis players aged between 17 and 27 years were recruited and participated in the present study. Among these recruited female participants, 10 tennis players had an international ranking (20.4±3.6 years, 170.3±5.4 cm and 61.9±6.9 kg), whereas 12 players had a national ranking (21.3±3.9 years, 168.9±4.4 cm and 62.8±9.5 kg). The average starting age of tennis play and weekly training volume was 6.2±1.5 years and 17.2±3.0 hours for the internationally ranked players versus 5.9±1.3 years and 6.2±2.4 hours for the nationally ranked players, respectively.

Procedures and Measurements

Data collection took place in the biomechanics laboratory facilities of the Vrije Universiteit Brussel (Belgium). Participants were asked to fill in a questionnaire upon arrival to provide some basic demographic and sport-specific information (i.e., date of birth, preferred upper extremity, one or two-handed backhand, starting age of playing tennis and average weekly training volume over the last year). Wearing minimal sports clothing and being barefooted, the participants' body height and weight were measured to the nearest 0.1 cm and 0.002 kg, using a stadiometer (SECA 217, Hamburg, Germany) and precision scale (WLT 60/120/X/L3 All scales Europe, Veen, The Netherlands), respectively. Subsequently, the participants performed a standardised 10-minute warm-up, involving different light running exercises as well as dynamic stretches, before completing the physical performance test battery.

The participants were instructed to wear their normal tennis outfit and sports shoes while executing the different physical performance tests. The composed field-based test battery included a total of 8 tests, to which the participants were familiarised beforehand. The different tests were always completed in the same order, ensuring alternation in testing the upper versus the lower extremities. Each subject was given three attempts per body side for every single test. The first attempt of a test was always performed with the right body side whereas the second attempt was always performed with the left body side, ensuring alteration between both sides of the body during testing. Participants were given 60 seconds of rest between attempts and 3 minutes of rest between tests to ensure sufficient recovery. The dominant performance value was defined as the overall best or fastest result of a specific test. The non-dominant performance value was defined as the best or fastest result of the same test with the corresponding upper or lower extremity (22). To examine the magnitude of functional asymmetry, side-to-side differences between the dominant and non-dominant performance value were calculated for every outcome measure linked to the different unilateral tests and expressed as a percentage by using the percentage difference method (PDM), with the formula : (dominant performance value – non-dominant performance value) / dominant performance value) * 100 (23).

Upper Extremity Tests

Handgrip strength (HGS): the participants were instructed to squeeze as hard as possible for three seconds in a digital handheld dynamometer with an accuracy of 0.1 kg (Jamar Plus, Patterson Medical, Nottinghamshire, United Kingdom) while being seated in a chair without arm rests. The participants held their elbow 90% flexed and movements of the upper extremity, such as extending the forearm, were not allowed (24).

Seated shot-put throw (SSPT): the participants were seated on the ground with their back against the wall and hips, knees and ankles parallel to the ground. The non-throwing arm was placed across the chest on to the opposite shoulder. The participants were instructed to throw a 3-kg medicine ball as far as possible in a forward direction. The distance where the ball strikes the ground first was measured to the nearest 1 cm using a tape measure (25).

Plate tapping (PT): two discs with a diameter of 20 cm were placed with their centres 60 cm apart on a table, whilst a 10 x 20 cm rectangle was placed in between both discs. The subject started the test with one hand placed on a disc and the other hand held fixed on the rectangle. The aim of this test was to move the one hand back and forth between both discs over the other hand in the middle as fast as possible. This action was repeated for 25 full cycles (i.e., 50 taps on the discs) and the time needed to complete this plate tapping test was recorded to the nearest 0.01 second using a hand-held stopwatch (26).

Lower Extremity Tests

Single leg countermovement jump (SL CMJ): the participants were instructed to jump up as high as possible on one leg whilst holding their hands on their hips. Swinging of the non-jumping leg was not allowed and the jumping leg had to remain fully extended throughout the flight phase. The participants needed to keep their balance after landing, otherwise they were provided with an extra attempt after the specified rest period. Jumping height was determined to the nearest 0.1 cm using the Optojump Next system (Microgate Bolzano, Italy).

Single leg forward hop test (SL FHT): the participants stood on one leg behind a tape line with their hands on their hips. The participants were instructed to jump as far as possible in a forward direction whilst landing on the same foot without losing their balance (e.g. moving their foot on which they land or planting the other foot to the ground). The distance covered from the marked start line to the heel of the participants landing foot was measured to the nearest 1 cm using a tape measure (27).

6 m single leg hop test (6m SL HT): the participants had to cover 6 m as fast as possible whilst hopping on one leg. The time needed to cover these 6 m was measured to the nearest 0.001 second using electronic timing gates (Witty Wireless Training Timer, Microgate, Bolzano, Italy). The timing gates were placed at hip height and the participants were instructed to start behind a tape line which was located 30 cm from the first timing gate.

505 change of direction time (505 COD time) and deficit (505 COD deficit): Participants' 10 m sprint time was assessed first using electronic timing gates (Witty Wireless Training Timer, Microgate, Bolzano, Italy). To determine their 505 COD time to the nearest 0.001 second, the 505 COD test was performed consisting of a 5 m sprint, followed by a 180° turn to either the left or the right side, and a 5 m sprint back to the marked start line. Participants were instructed to start the test behind a tape line which was located 30 cm from the timing gate. Participants'

505 COD deficit was subsequently calculated by subtracting their 10 m sprint time from their 505 COD time (28).

Y-balance test: the participants stood with one foot on the central plate of the Y-balance test kit whilst reaching as far as possible with their other foot in three different directions (anterior (Y ANT), posteromedial (Y PM) and posterolateral (Y PL)) without losing their balance. Distance reached in each direction was recorded to the nearest 0.1 cm (29).

Statistical Analysis

Data analysis was conducted using SPSS version 27.0 (SPSS Inc., Chicago, IL, USA). At total sample level, the outcome measures of every test and the functional asymmetry magnitudes were verified for normality of distribution using the Shapiro-Wilk test. Independent samples t-tests were used to examine differences in anthropometric and sport-specific information between the internationally and nationally ranked tennis players to describe the study sample. Within session variability and reliability of each test included in the composed physical performance test battery was calculated using the coefficient of variation (CV) and intraclass correlation coefficient (ICC), respectively. CV values < 10% were considered acceptable (30), whereas ICC values were classified as poor (<0.50), moderate (0.50–0.74), good (0.75–0.90) and excellent (>0.90) (31). Two-way repeated measures ANOVAs were used to compare the dominant versus the non-dominant performance values (i.e., within-subjects factor) of the internationally versus nationally ranked tennis players (i.e., between-subjects factor). Effect size analyses using Hedges g were conducted and classified as trivial (< 0.20), small (0.20–0.49), medium (0.50–0.79) or large (>0.80) (32). To examine whether the magnitude of functional asymmetry differed between internationally and nationally ranked players, Mann-Whitney U tests were used. The consistency, as to which extremity displayed the dominant performance value across tests, was examined by calculating Kappa coefficients, which were classified as 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 (1.00) (33). All data are presented as means ± standard deviations, and p-values below 0.05 were considered statistically significant.

Results

Except for the calculated functional asymmetry magnitudes (in %, quantified using the PDM), all outcome measures of interest were normally distributed. Regarding the anthropometric and sport-specific information, only the average weekly training volume (over the last year) was found to be significantly higher (t=4.954; p<0.001) in the internationally (17.2±3.0 hours) versus nationally ranked players (6.2±2.4 hours). All included female tennis players were right-handed and had a two-handed backhand, except for 2 nationally ranked players as one of them was left-handed and the other had a one-handed backhand. Every single test included in the composed physical performance test battery, showed acceptable variability (all CVs <10%) and excellent reliability (all ICCs >0.90; Table 1).

*** Table 1 around here ***

The whole-body functional asymmetries values of the internationally and nationally ranked players are displayed in Table 2. At the upper extremity level, our analyses demonstrated a significant magnitude of functional asymmetry for HGS (F=37.221, p<0.001), SSP (F=87.781, p<0.001) and PT (F=24.580, p=0.001), regardless of the female tennis players' performance level (effect size range=0.51-0.99). The magnitude of functional asymmetry did not differ between the internationally and nationally ranked players included in our sample.

At the lower extremity level, a significant magnitude of functional asymmetry was found for the SL CMJ (F=37.193, p<0.001), SL FHT (F=24.934, p=0.001), 6 m SL HT (F=16.618, p=0.002), 505 COD time (F=27.668, p=0.001), 505 COD deficit (F=8.576, p=0.017), Y ANT (F=21.580, p=0.004), Y PM (F=11.104, p=0.016) and Y PL (F=15.633, p=0.008) test items, regardless of the female tennis players' performance level (effect size range=0.23-0.78). Yet, the internationally ranked players performed significantly better regarding both the dominant and non-dominant performance value for the SL CMJ (F=9.576, p=0.013), SL FHT (F=9.767, p=0.012), 6 m SL HT (F=5.347, p=0.046), 505 COD time (F=7.385, p=0.026) and 505 COD deficit (F=5.611, p=0.034) outcome measures. Only for the SL FHT (U=25.0, p=0.020), the magnitude of functional asymmetry was significantly higher in the nationally compared to the internationally ranked players.

*** Table 2 around here ***

Owing the variable nature of asymmetry, individual asymmetry scores for all tests of the upper (Figure 1) and lower extremity (Figure 2) are provided. Since asymmetry magnitudes should be reported in the context of the CV, the dotted lines indicate when a player's asymmetry magnitude exceeds the test variability. Kappa coefficients showed perfect levels of agreement for all upper extremity tests (k=1.00), whereas levels of agreement for the lower extremity were much more variable (k range= -0.067 to 0.174; Table 3).

*** Table 3 around here ***

Figure 1 around here

Figure 2 around here

Discussion

The present study aimed to examine and compare the magnitude of whole-body functional asymmetries in internationally versus nationally ranked female tennis players using a comprehensive field-based physical performance test battery. The results of this study demonstrate significant functional asymmetries in both the upper and lower extremities of the included female tennis players, regardless of their performance level. The internationally ranked female tennis players performed significantly better on the jumping (i.e., SL CMJ and SL FHT), speed (i.e., 6m SL HT) and COD (i.e., 505 COD time and deficit) based lower extremity tests when compared to the nationally ranked players, whilst the magnitude of functional asymmetry for the SL FHT was significantly higher in the nationally ranked tennis players. For the direction of asymmetry, Kappa coefficients revealed perfect levels of agreement for the upper extremity between tests, but only slight to poor levels of agreement for the lower extremity.

Concerning the upper extremity, all participants performed significantly better on HGS, SSPT and PT with the preferred upper extremity, which consistently displayed the dominant performance value, compared to the contralateral upper extremity. The magnitudes of functional asymmetry in terms of HGS reported in this study are in accordance with previous studies in recreational adult tennis players (13.3%), and can be attributed to the unilateral nature of tennis as the preferred upper extremity is typically loaded more when executing a variety of different tennis strokes (10, 34). Similarly, it can be argued that the significantly higher score on the SSPT and PT when using the preferred upper extremity results from the repetitive use of this preferred upper extremity associated with tennis play (9). However, to the best of our knowledge, this is the first study to examine and report upper extremity functional asymmetry in tennis players using SSPT and PT. Given significant differences were evident between body sides for the upper extremity tests, it is not entirely unsurprising that the majority of players exhibited asymmetries greater than the CV (23). As such, these players (19 out of 22 for HGS, 21 out of 22 for SSPT and 19 out of 22 for PT) demonstrated 'real' asymmetries, as indicated by their values exceeding the dotted line on Figure 1. Furthermore, these real inter-limb differences in functionality at the upper extremity level were comparable according to players' performance level (i.e., internationally vs. nationally ranked players). Albeit lower than the magnitude of upper extremity asymmetry, the overall magnitude of asymmetry at lower extremity level ranged from 1.8-9.4% indicating significant functional asymmetries for all lower extremity tests, with the highest percentage difference being found for the SL CMJ. Although this result is in agreement with previous studies that have reported jump height from the SL CMJ as being a sensitive physical performance test to detect functional asymmetries, the magnitude of asymmetries reported in the present study (7.5-9.4%) were lower compared to previously performed studies in youth tennis players (14.7%) (17, 35).

The results of the present study demonstrate a significantly better performance of the internationally ranked players for the jumping (i.e., SL CMJ and SL FHT), speed (i.e., 6m SL HT) and COD (i.e., 505 COD time and deficit) based tests compared to the nationally ranked players. A possible explanation for these results, besides a potential difference in skill level, is the difference in average training volume as internationally ranked players were found to train significantly more compared to the nationally ranked players and could, therefore, perform physically better. Interestingly, the SL FHT was the only test of the test battery to show a significantly higher magnitude of functional asymmetry of the nationally ranked players. The small sample size and the large standard deviations reported in this study could potentially explain this finding. Therefore, it remains uncertain whether a reduction in functional asymmetry could be advantageous and considered a viable aim during targeted training interventions (3). It could, for instance, be that the functional asymmetries reported in this study are necessary adaptations required to perform tennis effectively (36). Interestingly, the players of the current study displayed a mean difference of 4.3 cm (for the internationally ranked players) and 5.6 cm (for the nationally ranked players) of the Y ANT, which could be relevant as an asymmetry of the Y-balance of more than 4 cm in the anterior direction is reported to increase lower extremity injury risk by two and half times (37). Therefore, it remains to be investigated whether functional asymmetries are indeed associated with a decreased sport-specific performance and/or increased injury risk and that targeted training interventions are justified.

This study compared the dominant versus the non-dominant performance value to examine and report lower extremity asymmetries as opposed to using the values of the self-reported preferred lower extremity by asking, for example, which leg participants prefer to perform a single leg hop or to kick a ball. Hence, the dominant performance value was chosen due to a low agreement between the reported preferred extremity and dominant performance value as it is described that the reported preferred extremity did not always display the best or highest test value (23, 38). The latter could subsequently lead to an incorrect calculation of the magnitude of asymmetry as a percentage should be calculated with respect to the best performance value (23). Additionally, and besides being movement or task specific, asymmetries are reported to be direction specific (39-41). The latter was apparent in the lower extremities of the female tennis players included in this study as kappa coefficients indicated only slight to poor levels of agreement for the direction of imbalance, between tests (40, 42). This was in contrast to the upper extremity, displaying perfect consistency in this respect. As such, these data indicate a consistently preferred limb for the upper extremity, regardless of the test selected. In contrast, the lower extremity highlights the task-specific nature of asymmetry for the selected tests, with kappa values in the present study comparable to previous research using this method of analysis for inter-limb asymmetry (7). Thus, given the inherent variability in these results for the lower extremity, it is highly recommended that asymmetries should be monitored individually in order to make an asymmetry profile for each (tennis) player or athlete, which is again, in line with recent suggestions for this topic (4). Furthermore, and due to the movement specificity of asymmetries, more than one physical performance test should be used to provide an accurate profile when examining functional asymmetries. This is especially the case in unilateral sports, such as tennis requiring a range of physical competencies and COD in multiple directions (i.e., forward, backward and/or side-ways) (8).

Although this is the first study to examine whole-body functional asymmetries in female tennis players using a comprehensive physical test battery, some limitations are apparent. For instance, this study had a small sample size (although a post-hoc power analysis revealed that the statistical power of this study was 91%), implemented a cross-sectional design and did not include a control group consisting of non-athletes. In addition, the relationship between functional asymmetry and decreased performances as well as injury incidence was not examined. Therefore, future longitudinal research is needed to examine the influence of functional asymmetries on sports-specific performance and injury incidence with the inclusion of a control group.

Conclusions

To conclude, the comprehensive field-based functional test battery described in this study showed to be reliable to examine (the magnitude of) whole-body functional asymmetries. Subsequently, the elite female tennis players included in this study displayed significant whole-body functional asymmetries ranging from 8.9% to 15.2% for the upper extremity and from

1.9% to 9.4% for the lower extremity. Regardless of test selection, the preferred upper extremity consistently displayed the dominant performance value indicating true limb dominance. In contrast to the upper extremity, the poor levels of agreement across tests for the lower extremity illustrate the direction variability of lower extremity functional asymmetries. Due to this direction variability, it is encouraged to monitor functional asymmetries individually to generate an asymmetry profile for each player or athlete.

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Notes

Conflicts of interest — There is no conflict of interest to report.

Authors' contributions — Laurent Chapelle recruited the participants, collected all data and also took responsibility for data analysis and drafting the manuscript. Chris Bishop, Peter Clarys and Eva D'Hondt substantially contributed to the conception of the design, the interpretation of the data and they critically revised the manuscript's drafting. All authors read and approved the final version of the manuscript.

TABLES

Table 1. Variability and reliability of the unilateral tests of the field-based physical performance test battery.

Functional tests	CV	ICC (95% CI)
Upper extremity tests		
Handgrip strength	2.9	0.966 (0.955–0.985)
Seated shot-put throw	4.8	0.955 (0.914–0.980)
Plate tapping	3.8	0.949 (0.898–0.978)
Lower extremity tests		
Single leg countermovement jump	5.9	0.977 (0.956–0.990)
Single leg forward hop test	3.5	0.984 (0.969–0.993)
6 m single leg hop test	2.4	0.984 (0.955–0.997)
505 changes of direction:		
Time	1.5	0.986 (0.960–0.997)
Direction	3.9	0.974 (0.925–0.995)
Y-balance test:		
Anterior	4.0	0.961 (0.926–0.983
Posteromedial	4.4	0.968 (0.933–0.988)
Posterolateral	4.1	0.904 (0.765–0.967)

Note: CV = coefficient of variation; ICC = intraclass correlation coefficient; 95% CI = 95% confidence intervals.

Table 2. Upper and lower extremity functional asymmetry values according to female tennis players' performance level.

Functional tests	Internationally ranked players (n = 10)				Nationally ranked players (n = 12)			
	D value	**ND value**	**ES (95% CI)**	**PDM (%)**	**D value**	**ND value**	**ES (95% CI)**	**PDM (%)**
Upper extremity tests								
HGS (kg) $^{\Delta}$	39.6 ± 7.0	35.3 ± 6.6	0.61 (-0.15-1.36)	10.8 ± 6.3	38.3 ± 6.8	32.6 ± 5.0	0.92 (0.22-1.63)	15.2 ± 9.5
SST (cm) $^{\Delta}$	332.4 ± 32.7	298.3 ± 33.0	0.99 (0.21-1.77)	10.3 ± 4.0	324.7 ± 55.8	295.5 ± 52.9	0.51 (-0.23-1.26)	8.9 ± 5.9
PT (sec) $^{\Delta}$	10.15 ±1.52	11.32 ± 1.70	0.69 (-0.06-1.45)	10.2 ± 5.6	10.31 ± 1.56	11.60 ± 1.86	0.72 (-0.04-1.48)	11.8 ± 6.5
Lower extremity tests								
SL CMJ (cm) $^{\$\Delta}$	16.3 ± 2.6	14.5 ± 2.0	0.74 (-0.02-1.50)	9.4 ± 6.9	13.1 ± 3.1	12.3 ± 2.5	0.27 (-0.47-1.01)	7.5 ± 5.8
SL FHT (cm) $^{\$\Delta}$ *	152.5 ± 12.3	148.5 ± 13.1	0.30 (-0.44-1.04)	2.9 ± 3.4	132.9 ± 15.6	124.1 ± 16.1	0.53 (-0.22-1.28)	6.3 ± 4.3
6m SL HT (sec) $^{\$\Delta}$	1.891 ± 0.159	1.955 ± 0.147	0.40 (0.34-1.14)	3.7 ± 3.9	2.005 ± 0.151	2.078 ± 0.173	0.43 (-0.31-1.17)	3.4 ± 2.6
505 COD								
Time (sec) $^{\$\Delta}$	3.158 ± 0.131	3.219 ± 0.136	0.44 (-0.31-1.18)	1.8 ± 1.5	3.313 ± 0.183	3.383 ± 0.187	0.36 (-0.38-1.10)	2.1 ± 1.9
Deficit (sec) $^{\$\Delta}$	1.109 ± 0.119	1.127 ± 0.093	0.23 (-0.48-0.90)	3.4 ± 2.1	1.178 ± 0.109	1.248 ± 0.106	0.62 (-0.13-1.38)	5.1 ± 4.9
Y-balance								
Y ANT (cm) $^{\Delta}$	67.1 ± 5.4	62.8 ± 4.5	0.76 (0.06-1.50)	6.2 ± 4.6	67.7 ± 9.2	62.1 ± 8.2	0.62 (-0.14-1.37)	8.1 ± 5.8
Y PM (cm) $^{\Delta}$	106.0 ± 9.7	101.1 ± 9.5	0.49 (-0.26-1.24)	4.3 ± 3.7	99.5 ± 8.3	96.3 ± 7.4	0.39 (-0.32-1.10)	3.6 ± 2.7
Y PL (cm) $^{\Delta}$	111.6 ± 9.3	106.4 ± 8.6	0.56 (-0.19-1.31)	5.1 ± 4.8	106.4 ± 8.6	99.6 ± 8.1	0.78 (0.05-1.51)	5.9 ± 6.8

Note: data are presented as mean ± standard deviation; D value = dominant performance value; ND value = non-dominant performance value; ES = effect size; 95% CI = 95% confidence interval; PDM = percentage difference method; HGS = handgrip strength; SST = seated shot-put throw; PT = plate tapping; SL CMJ = single leg countermovement jump; SL FHT = single leg forward hop test; 6m SL HT = 6 m single hop test; COD = changes of direction; Y ANT = Y-balance test, anterior; Y PM = Y-balance test, posteromedial; Y PM = Y-balance test, posterolateral.

*$^{\$}$ Significantly (p<0.05) better dominant and non-dominant performance value of the internationally ranked players compared to the nationally ranked players, $^{\Delta}$ Significant (p<0.05) degree of asymmetry between the dominant and non-dominant performance value, * Significantly (p<0.05) higher degree of asymmetry of the nationally ranked players compared to the internationally ranked players.*

Table 3. Kappa coefficients comparing the consistency as to which lower extremity displayed the dominant value for different tests at the upper and lower extremity level.

Test comparison	Kappa coefficient	Description
Upper extremity		
Handgrip strength – Seated shot-put throw	1.000	Perfect
Handgrip strength – Plate tapping	1.000	Perfect
Seated shot-put throw – Plate tapping	1.000	Perfect
Lower extremity		
Single leg countermovement jump – Single leg forward hop test	0.174	Slight
6 m single leg hop test – Single leg countermovement jump	-0.067	Poor
6 m single leg hop test – single leg forward hop test	0.040	Slight
Y balance, anterior – Y balance, posteromedial	-0.005	Poor
Y balance, anterior – Y balance, posterolateral	0.034	Slight
Y balance, posterolateral – Y balance, posteromedial	0.066	Slight

Note: Kappa coefficients are classified as 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 (1.00) (33).

FIGURES

Figure 1. Individual degree and direction of upper extremity functional asymmetry in internationally (n = 10) and nationally (n = 12) ranked female tennis players.
Note: a positive % indicates that the preferred upper extremity displayed the dominant performance value, whereas a negative % indicates that the non-preferred upper extremity displayed the dominant performance value. Dotted line indicates the coefficient of variation.

Figure 2. Individual degree and direction of functional lower extremity asymmetry in internationally (n = 10) and nationally (n = 12) ranked female tennis players.
Note: a positive % indicates that the right lower extremity displayed the dominant performance value, whereas a negative % indicates that the left lower extremity displayed the dominant performance value. Dotted line indicates the coefficient of variation.

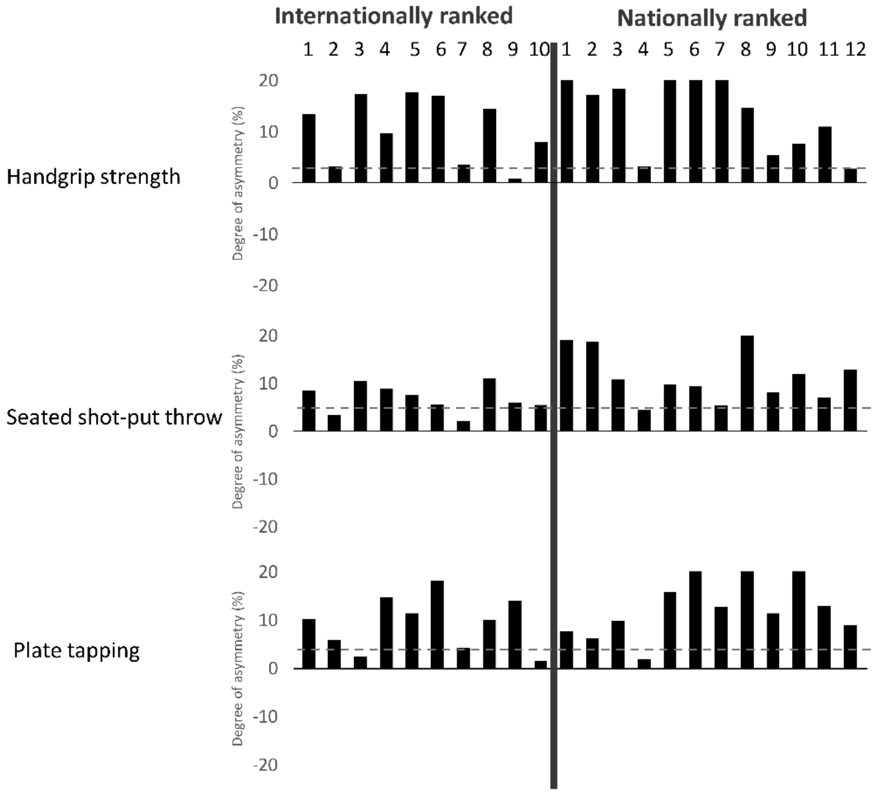

Figure 1. Individual degree and direction of upper extremity functional asymmetry in internationally (n = 10) and nationally (n = 12) ranked female tennis players.

Note: a positive % indicates that the preferred upper extremity displayed the dominant performance value, whereas a negative % indicates that the non-preferred upper extremity displayed the dominant performance value. Dotted line indicates the coefficient of variation.

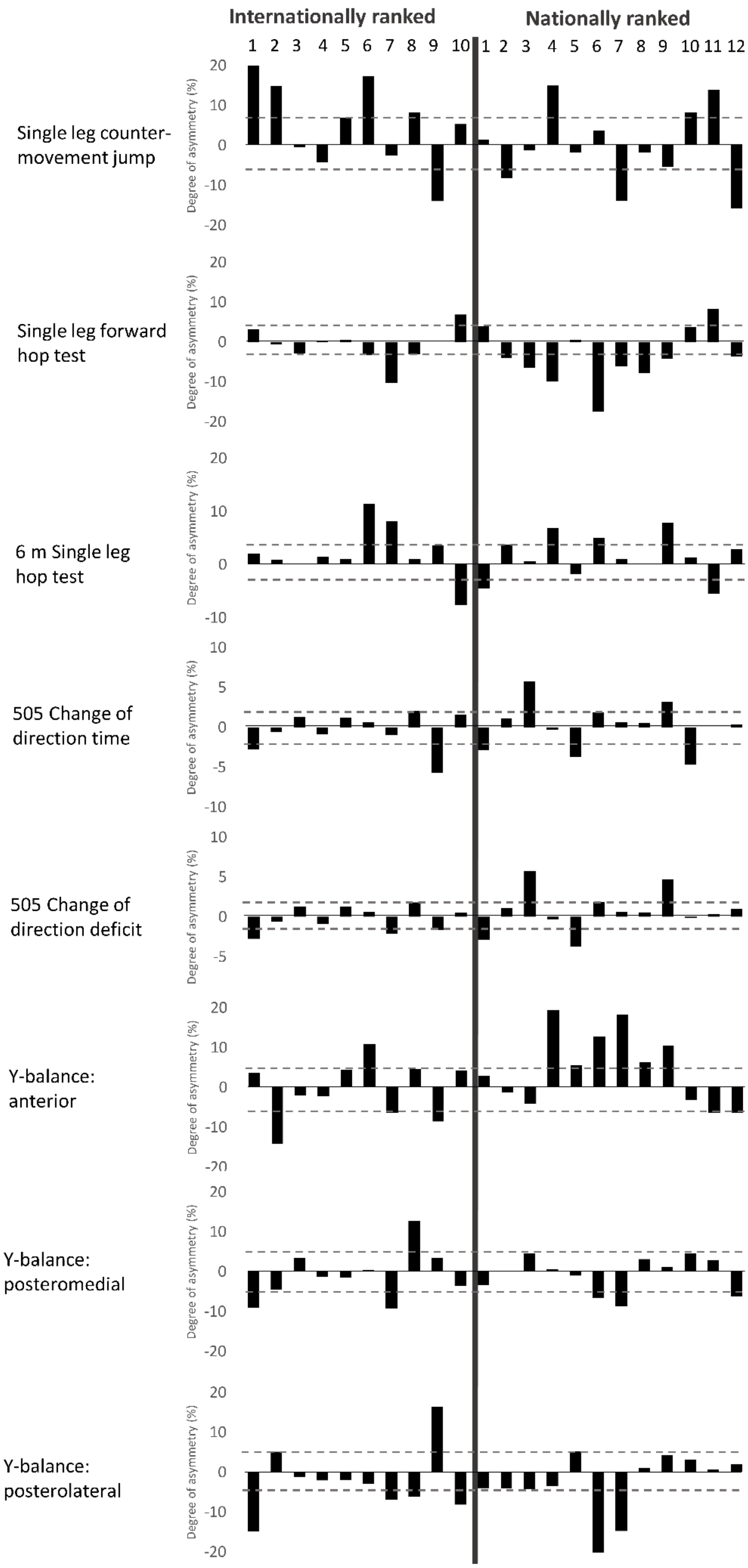

Figure 2. Individual degree and direction of functional lower extremity asymmetry in internationally (n = 10) and nationally (n = 12) ranked female tennis players.

Note: a positive % indicates that the right lower extremity displayed the dominant performance value, whereas a negative % indicates that the left lower extremity displayed the dominant performance value. Dotted line indicates the coefficient of variation.