DIFFERENCES IN TENNIS SERVE KINEMATICS BETWEEN ELITE ADOLESCENT MALE AND FEMALE PLAYERS

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The purpose of this study was to compare kinematic differences in elite adolescent male and female tennis serves. A 3D motion capture system was used to capture whole body, racquet and ball toss kinematics while twenty elite adolescent tennis players (male = 10, female = 10) performed flat and kick serves. Females had greater vertical front hip velocity (FS: 0.2 m/s, KS: 0.2 m/s greater than males), whilst males experienced larger peak shoulder external rotation displacements in both flat (10° greater) and kick (8° greater) serves compared to females. Females tossed the ball higher (FS: 18 cm, KS 19 cm) whilst males impacted the ball more laterally (across the body) (FS: 17cm, KS: 12) and more forward (FS: 10 cm, KS: 13 cm) into the court. Females had greater lower body kinematics whereas males tended to rely on shoulder external rotation to produce ball speed.

KEY WORDS: biomechanics, sport, technique,

INTRODUCTION: The tennis serve is a crucial stroke in tennis as it is the only stroke that players have full control over, and if executed well, can allow the serving player to win points with immediate effect. Historically, a large portion of tennis research has investigated the serve in males, until recent work by Whiteside, Elliott, Lay, & Reid (2013) explored the different flat serve kinematics across females of different maturity status. Previous work has compared the serves of both genders though, with Fleisig, Nicholls, Elliott, & Escamilla (2003) showing that males have significantly greater shoulder internal rotation angular velocity when compared to their female counterparts (m: 2420°/s and f: 1370°/s respectively). This research however has been limited to adult populations, meaning that there is little evidence to steer the instruction of the junior serve. Given that adolescence is a crucial period for growth and development and generally coincides wirth when the kick serve is introduced to players, it is important to investigate the serve and joint mechanics in this context (Abrams, Renstrom, & Safran, 2012). An improved understanding of age appropriate serve kinematics will mean that players no longer must rely on simply emulating their adult professional counterparts and may also be better equipped to avert serve-related injuries. The aim of this study was therefore to compare the serve kinematics of adolescent female and male tennis players. We hypothesize that lower body, trunk and upper body kinematics will differ between males and females.

METHODS: Twenty (male: 10, female: 10) right-handed elite adolescent tennis players (mean age: 12.6, SD: 1.2 years), were recruited for this study. Participants were excluded if they had a current performance inhibiting injury, were ill, or experienced pain at the time of testing. Ethical approval was obtained from the Victoria University Human Research Ethics Committee and participants provided voluntary informed consent and assent prior to any involvement in the study.

All data were collected on indoor hard courts at the Tennis Australia National Academy in Melbourne. Prior to testing, participant height, weight and racquet parameters (mass, centre of mass (COM), swingweight, spinweight and polar moment of inertia) were recorded. Retroreflective markers (12 mm diameter) and clusters on rigid plates were attached to the skin on relevant segments and anatomical landmarks (lower body, trunk and upper body, racquet and ball) using double-sided tape. Marker trajectories were recorded using a 12-camera opto-reflective motion capture system (Vicon Motion Systems Ltd, Oxford, UK; 250 Hz). Once markers were attached, players completed a self-directed warm up followed by subject specific calibration trials. Participants completed a series of serves aiming toward 1m x 2m target area on the deuce court at the “T”. The players performed maximal effort flat serves

(FS) followed by kick serves (KS) with successful serves being defined as those which landed in the target area. Marker positions were recorded by the motion capture system for each serve. Serving continued until three successful FS and KS were completed in accordance with prior established methods (Campbell, O'Sullivan, Straker, Elliot & Reid, 2014; Campbell, Straker, O'Sullivan, Elliot & Reid, 2013).
The data were processed and treated using Vicon Nexus software (Vicon Motion Systems Ltd, Oxford, UK) and a cubic-spline was used to fill gaps within marker trajectories. Trajectories were filtered using a Woltring filter with a mean square error of 0.2. Markers on the left arm, ball and racquet were used to identify the frame for ball release and impact as well as four key time points within each serve to define phases as per previous research (Whiteside, Elliott, Lay, & Reid, 2013); ball release/toss (BT), racquet high point (RHP), racquet low point (RLP) and impact. Independent t-tests were used to assess differences between gender with an alpha of 0.05.

RESULTS: There were several significant findings when comparing male and female serve kinematics as seen in Tables 1 and 2. Females had significantly greater vertical front hip velocity in the FS (F: 1.5 ± 0.2 m/s, M: 1.3 ± 0.3 m/s, p<0.01) and KS (F: 1.6 ± 0.3 m/s, M: 1.4 ± 0.3 m/s, p<0.01). However maximum shoulder external rotation displacement was greater among the male players in both FS (M: -128 ± 16°, F: -118 ± 9°, p<0.01) and KS (M: -124 ± 11°, F: -116 ± 17°). In relation to ball toss and impact kinematics, females had a higher ball toss (Mean difference; FS: 18 cm, KS 19 cm, p<0.05) compared to males, which resulted in a larger ball drop distance (MD; FS: 18 cm, KS: 21 cm, p<0.05). Males however, impacted the ball more laterally (across their body) whereas females tended to contact the ball more centrally (MD; FS: 17 cm, KS: 12 cm, p<0.01). Males also had a significantly greater impact height to stature ratio during the FS compared to females (M: 0.68 ± 0.05, F: 0.65 ± 0.02, p<0.05).

Table 1: Upper body, trunk and lower body kinematics

Variable	Flat Serve		Kick Serve	
	Female	Male	Female	Male
Left Knee Angle (◦)	111 ± 10	112 ± 5	112 ± 10	111 ± 7
Right Knee Angle (◦)	104 ± 11	105 ± 12	105 ± 11	105 ± 14
Front Leg Triple Extension (◦/sec)	875 ± 263	788 ± 201	907 ± 226	888 ± 229
Back Leg Triple Extension (◦/sec)	771 ± 371	728 ± 224	736 ± 258	750 ± 207
Front Hip Vertical Velocity (m/s)	1.5 ± 0.2	1.3 ± 0.3**	1.6 ± 0.3	1.4 ± 0.3##
Back Hip Vertical Velocity (m/s)	2 ± 0.3	1.9 ± 0.3	2.1 ± 0.3	2.1 ± 0.3
Separation Angle (◦)	-9 ± 1	-8 ± 2	-7 ± 1	-8.9 ± 12.9
Max Shoulder External Rotation (◦)	-118 ± 9	-128 ± 16**	-116 ± 17	-124 ± 11#
Max Shoulder Internal Rotation (◦/sec)	1561 ± 512	1610 ± 470	1378 ± 493	1355 ± 498
Max Elbow Extension (◦/sec)	-1438 ± 299	-1346 ± 220	-1316 ± 268	-1231 ± 272
Max Elbow Pronation (◦/sec)	680 ± 247	597 ± 255	551 ± 199	546 ± 243
Shoulder Abduction Angle @ Impact (◦)	111 ± 10	110 ± 9	113 ± 8	111 ± 8
Max Racquet Velocity (m/s)	35 ± 3	36 ± 5	33 ± 4	34 ± 5

*Represents significance of p<0.05 in comparing the males' FS to the females' FS; **Represents significance of p<0.01 in comparing the males' FS to the females' FS; #Represents significance of p<0.05 in comparing the males' KS to the females' KS; ##Represents significance of p<0.01 in comparing the males' KS to the females' KS.

Table 2: Ball toss and impact kinematics

Variable	Flat Serve		Kick Serve	
	Female	Male	Female	Male
Toss Height (cm)	329 ± 20	311 ± 33*	330 ± 23	311 ± 27##
Toss Height : Stature (ratio)	0.50 ± 0.03	0.56 ± 0.05	0.50 ± 0.04	0.55 ± 0.05
L - R Impact Position (cm)	9 ± 24	26. ± 18*	28 ± 21	40 ± 22#
Forward Impact Position (cm)	42 ± 11	52 ± 30**	25 ± 13	38 ± 15##
Impact Height (cm)	246 ± 10	246 ± 17	246 ± 12	248 ± 18
Impact Height Stature (ratio)	0.65 ± 0.02	0.68 ± 0.05*	0.66 ± 0.03	0.67 ± 0.03
Drop Distance (cm)	84 ± 20	66 ± 34*	84 ± 24	63 ± 25##

*Represents significance of $p<0.05$ in comparing the males' FS to the females' FS; **Represents significance of $p<0.01$ in comparing the males' FS to the females' FS; #Represents significance of $p<0.05$ in comparing the males' KS to the females' KS; ##Represents significance of $p<0.01$ in comparing the males' KS to the females' KS.

DISCUSSION: When comparing male and female lower body kinematics, females had a significantly greater front hip vertical velocity in both FS and KS compared to males. Although not significant, females also had more triple joint extension (sum of angular hip, knee and ankle extension velocity) in both front (FS: 875.0°/s, KS: 907°/s) and back (FS: 771.4 °/s, KS: 736.4°/s) leg drive, pointing to evidence of greater leg drive among adolescent females. These findings reinforce research by Reid, Elliott, & Alderson (2007) who concluded that whilst knee angles are easily observable for coaches, they should not be the singular component evaluated when assessing "leg drive".

Males had significantly greater peak shoulder external rotation displacements when compared to females, which were 10° and 8° greater in both FS and KS respectively. Interestingly, previous reports have shown high performance males experience 115.9 ± 18.3° of external rotation (Reid, Elliot & Alderson, 2007) while the same angles for prepubescent and pubescent female players have been recorded as 129° and 136° respectively (Whiteside et al., 2013). Indeed, it is interesting to note that previous research has stated that a vigorous leg drive aids greater shoulder external rotation (Bonnefoy, Slawinski, Leveque, Riquet & Miller 2009). Our results were not as emphatic in this regard as females had a more vigorous leg drive but males had a significantly greater peak shoulder external rotation angles. A possible explanation for these findings is that male players rely more on upon trunk and upper body strength to generate ball speed drive, though even this seems unlikely given the similarity in other upper body kinematics between the two genders.

Females had higher ball tosses than males, which consequently resulted in the ball dropping larger distances to impact. This extra ball flight time allowed the females to generate greater leg drive when compared to the males. Males tended to contact the ball more laterally (toward the left side of the body) in both FS and KS and hit the ball further into the court on KS compared to females. Although ball spin was not measured in the current study, the more central impact position of female players likely makes creating topspin on the kick serve more difficult. There was a notable difference between FS and KS impact locations which is to be expected. The FS had more central and forward impact locations consistent with hitting a flatter and faster serve. The kick serve on the other hand, was 14-19cm more lateral and 14-17cm closer to the baseline, which facilitates the racquet arc required to impart topspin to the ball. Female ball toss characteristics in this study were consistent with those described by Whiteside et al. (2013), however the male data differed from previous research. A study by Reid, Whiteside, & Elliott (2010) reported junior males to have similar forward impact locations, though approximately 8 cm greater lateral impact location and a ~30cm lower ball toss. When compared to older male players, our players had more lateral impacts on FS (~13cm) though similar lateral impact locations on KS. Impact locations were not as far in to the court on either FS or KS (~6cm and ~9cm respectively) (Reid, Whiteside, & Elliott, 2011). This highlights that younger players do not self-organise in the same way as older players and prepare their bodies and racquets differently to produce serves.

It is important to note that upper and lower body kinematics (angles and angular velocities) have been found to differ between older female (Fleisig, Nicholls, Elliot & Escamilla 2003;

Whiteside et al., 2013) and male (Reid et al., 2007) athletes. For example, maximum shoulder external rotation (MER) has been reported to be between ~115° to ~169° in professional male tennis players (Elliot, Fleisig, Nicholls, Escamilla 2003; Reid et al., 2007) and ~141° to ~171° in professional female tennis players (Whiteside et al., 2013). The difference between the minimum values reported for male and female MER is 26°. The gender-based difference for MER angle in our junior sample was 10° during the FS and 8° during the kick serve, which is considerably less than in adults. These findings add support to the notion that there are gender differences between elite adult and junior tennis players. Lastly, due to development constraints in the junior tennis serve (Whiteside et al., 2013), junior players who are encouraged to simply emulate older and more experienced players' service motion, with no consideration given to their physical maturity, may face more pronounced musculoskeletal injury risk.

CONCLUSION: This study quantified the differences between elite adolescent male and female player tennis serves. Females had greater front hip vertical velocity and tossed the ball higher in both flat and kick serves. Males had greater peak shoulder joint external rotation angles and more lateral impact position in flat and kick serves as well as more forward impact positions during kick serves. Comparison to previously published adult serve data suggests that effects for age and gender are likely evident, reinforcing the need for continued research. This data provides coaches and researchers with important reference points when analyzing the serves of elite junior players.

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