A4-6 ID44

THE FEMALE TENNIS SERVE: AN ANALAGOUS VERSION OF THE MALE SERVE?

Bruce Elliott[1], David Whiteside[1], Brendan Lay[1], Machar Reid[1,2]

[1]School of Sport Science, Exercise & Health, The University of Western Australia, Australia
[2] Sports Science & Medicine Unit, Tennis Australia, Australia.

The mechanics of the high-performance male tennis serve have received considerable research attention; however, the relevance of this knowledge to the female serve is largely unknown. To address this research void, 3D body, racquet and ball kinematics were recorded from eight professional female players hitting a 'first-power' serve, using a 22-camera VICON MX system operating at 500 Hz. The kinematic data were then compared with the corresponding male data in the literature that have been garnered from high-performance players. The female mean resultant racquet velocity was 0.86 of the value reported for male players, which mirrored the ratio of the highest velocity serve recorded on the respective professional circuits. While the majority of kinematic variables were similar between these two groups, the lesser shoulder internal rotation by the females (0.83) compared with the males helps to define the above velocity difference.

KEYWORDS: Gender, Power serve, Biomechanics, WTA professional

INTRODUCTION: The serve is a closed skill, allowing the performer to control all elements of its execution. This affords proficient servers a tactical advantage, as their serve can be used to gain the ascendency or even win a point outright. The importance of the first serve specifically, is reflected in the numerous investigations that have examined the mechanics of the stroke. The bulk of this work has focused on high-performance male players and has highlighted the importance of the lower limbs (Bonnefoy et al., 2009; Girard et al., 2005; Reid et al., 2008), trunk (Bahamonde, 2000; Chow et al., 2009; Fleisig et al., 2003) and serving arm (Bahamonde, 2005; Elliott et al., 1995; Reid et al., 2007; Tanabe & Ito, 2007) in the generation of racquet velocity. Where high-performance male players have benefited from the aforesaid research investment, female players have received comparatively less research interest. This disparity is even more surprising given the public and corporate investments into women's tennis, where almost US$100,000,000 in prize money was won on the WTA tour in 2012 (WTA, 2012). Devoid of empirical guidance, coaches of female players are often left to apply or extrapolate the available male data to their players. Such an approach seems rather misplaced, as observation and match-play data imply that gender influences serve performance. This view is offered support within the conditioning literature, where anthropometric and physiological differences are reported in absolute size, muscular strength, flexibility and power (Kraemer et al., 1995; Roetert et al., 1996); and in the motor control literature, where analogous movement patterns between genders are considered functionally improbable (Leversen et al., 2012).
The literature clearly confirms the expectation for physical and motor performance capacities to influence serve performance. In intending to determine if and where gender differences lie, key kinematic data recorded from a 3D analysis of the professional female (F) serve were nominally compared with male (M) data that have been reported in the literature.

METHODS: Eight professional female tennis players (mean age 21.3 ± 3.8 yrs; height 169.2 ± 4.8 cm and mass 61.9 ± 4.2 kg) with WTA rankings better than 325 participated in the study, which had been approved by the University of Western Australia's (UWA) Human Ethics Committee. All testing was completed at the Australian Institute of Sport indoor biomechanics laboratory on a full size court. Sixty retro-reflective markers, 14 mm in diameter were affixed to each player according to the UWA marker set (Besier et al., 2003; Lloyd et al., 2000). Three hemispherical markers, composed of ultra-light foam (radius 7 mm) were placed on each of the racquet and ball to create coordinate systems therein. Each player completed a 10-minute warm up and used her own racquet to complete the protocol. Players performed maximal effort ‘flat’ serves aiming for a 1 × 1 m target bordering the ‘T’ of the service box on the deuce court. Five blocks of eight serves were performed with a 2-minute rest period separating successive blocks. Three-dimensional marker positions were recorded using a 22-camera VICON MX system (VICON Motion Systems, Oxford, UK) operating at 500 Hz. Five of each player’s fastest serves landing in the target area were selected for analysis. Gaps in the raw marker trajectories were interpolated using a cubic spline within the VICON Nexus software. A second-order polynomial extrapolation specific to tennis limited the distortion of kinematic data around impact (Reid et al., 2012a). Data were subsequently filtered using a Woltring filter (Woltring, 1986), with the optimal mean squared error of 2 mm determined by a residual analysis, and then modelled using the UWA full body, racquet and ball marker models. With the exception of the shoulder, where a Y-X-Y decomposition was used, joint rotations were expressed using the Euler Z-X-Y sequence.

Analysis commenced at the instant the ball was released from the hand (BR), and ball zenith (BZ) represented the peak vertical displacement of the ball during its toss. The subsequent nadir of vertical racquet displacement was the racquet low point (RLP), which has been identified as coincident to a player leaving the ground (Bonnefoy et al., 2009). Impact was defined as 0.002 s prior to racquet-ball contact. Leg drive can be defined as the period from BZ to RLP, while RLP to impact is considered the forward-swing phase of the serve. From the female data one standard deviation was used as a guide to indicate a meaningful difference when compared with their male counterparts.

RESULTS AND DISCUSSION: The highest serve velocity recorded for professional female players is typically 0.84 that of male professionals (M~250 km/hr; F~210 km/hr; ATP and WTA website, 2012), a ratio which mirrors the resultant racquet velocity in this study (Table 1: M= 50 m/s, F= 43 m/s; ratio =0.86). The mean ball velocity of 44.4 m/s was higher than reported for two female professionals analysed by Lopez de Subijana and Navarro (2006-39.7 m/s) demonstrating the quality of this sample. However, the premise to be addressed was whether the female serve is a scaled-down version of the male counterpart or structured differently. Initially the discrete mechanics that underpin the service action will be discussed, followed by a review of the kinematic chain from a velocity generation perspective.

In professional players, the ball position at BZ transcended gender, where it was positioned in line with and 0.5 m forward of the front toe. However, it was higher, relative to standing height, for the female (2.0) compared with male players (~1.85). At impact, vertical ball position was similar for the two sexes when stature was taken into consideration (F & M =150%). Typically the ball was impacted to the left of the body for right-handed players, while male players impacted further inside the court (F=61 cm, M=78 cm).

Racquet velocity is built using all segments in the kinematic chain. While males typically flex the front knee more than females (F= 69°; M= 75°), the important back lower limb is flexed more by female players (F=88°; M=80°). Both the peak angular velocities at the respective knees reflect this flexion, as do the resulting linear vertical velocities of the hips, where the back hip records a higher value than that of the front (F=2.3; M=2.1 m/s). Drive from the lower limbs is then transferred to the trunk where, from a more rotated starting position (separation angles; F=17°; M=25°), male players developed slightly greater twist axis rotation (F=715; M=870 deg/s). A greater ‘shoulder-over-shoulder’ rotation may have occurred for the male professionals; however no angular momentum data are available for female players (Bahamonde, 2000).

External rotation at the shoulder was similar between female players and male players (F=141°; M=135°), yet the males were able to produce larger peak internal rotation velocity (F=2,000; M=2420 deg/s). The mean level of internal rotation angular velocity for the females was similar to the value reported in Lopez de Subijana and Navarro (2006) for a female professional with a similar service velocity. Interestingly, the female value was 0.83 that of the males – almost the exact ratio in racquet velocity at impact. Currently data on differences in peak internal rotation torques recorded on a dynamometer for both sexes are being investigated. These commensurate disparities in racquet and internal rotation velocity between genders may be explained by the fact that internal rotation velocity is the primary kinematic contributor to racquet velocity (Elliott et al., 1995). Accordingly, gender differences in internal rotation velocity appear to principally account for the discrepancies in serve velocity at the professional level. Elbow extension and wrist flexion velocities were both similar between genders. At impact, the shoulder abduction angle was similar between genders (~102°), and the elbow was slightly more flexed in the female players (F=27°; M=20°). The level of racquet resultant velocity, ball velocity and rotation were both greater for the male professional players.

Table 4: Mean mechanical aspects of the professional female and male tennis serve

Variable	**Female** (n=8) Mean ± SD	**Male data with ref. number**
Ball position at zenith (cm)		
Vertical	336 ± 16	338[17]
Forward	49 ± 4	47
Lateral (- to left for RH player)	-3 ± 13	2
Ball position at impact (cm)		
Vertical	254 ± 7	274[5]
Forward	61 ± 5	78
Lateral (- to left for RH player)	-14 ± 16	-16
Ball rotation (deg/s)	6359 ± 1746	7277[19, 20]
Lower Limbs		
Peak front knee flexion angle (°)	69 ± 8	75[15]
Peak back knee flexion angle (°)	88 ± 8	80[16]
Peak front hip vertical velocity (m/s)	1.7 ± 0.1	1.6[22]
Peak back hip vertical velocity (m/s)	2.3 ± 0.1	2.1[15,22]
Trunk		
Peak separation angle (°)	17 ± 11	25[7]
Peak twist (deg/s)	715 ± 145	870[8]
Peak shoulder-over-shoulder (deg/s)	700 ± 55	x
Transverse plane pelvis rotation at impact (°)	75 ± 6	x
Transverse plane trunk rotation at impact (°)	87 ± 7	87[17]
Serving arm		
Peak shoulder external rotation (°)	141 ± 7	135[21]
Peak shoulder internal rotation velocity (deg/s)	2,000 ± 297	2,420[8]
Peak elbow extension velocity (deg/s)	1524 ± 144	1510[8]
Peak wrist flexion velocity (deg/s)	1911 ± 264	1950[8]
Shoulder abduction angle at impact (°)	104 ± 13	101[8]
Elbow flexion angle at impact (°)	27 ± 8	20[8]
Racquet velocity at impact (m/s)	43 ± 3	50[17]

CONCLUSION: While many of the discrete mechanical variables transcend gender at the professional level, the magnitude of shoulder internal rotation velocity appears to differentiate male and female players. Consequently, technical instruction to players in the upper echelon of world tennis may proceed, largely, independent of gender.

REFERENCES

Bahamonde, R. (2000). Changes in angular momentum during the tennis serve. *Journal of Sports Sciences, 18*, 579-592.

Bahamonde, R. (2005). Review of the biomechanical function of the elbow during tennis strokes. *International Sports Medicine Journal, 6*(2), 42-63.

Besier, T., Sturnieks, D., Alderson, J. & Lloyd, D. (2003). Repeatability of gait data using a functional hip joint centre and a mean helical knee axis. *Journal of Biomechanics, 36*(8), 1159-1168.

Bonnefoy, A., Slawinski, J., Leveque, J. M., Riquet, A. & Miller, C. (2009). Relationship between the vertical racquet head height and the lower limb motions of elite players' flat serve. *Computer Methods in Biomechanics and Biomedical Engineering, 12*(1), 55-57.

Chow, J., Park, S. & Tillman, M. (2009). Lower trunk kinematics and muscle activity during different types of tennis serves. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology, 1*(1), 24-29.

Elliott, B., Marshall, R. & Noffal, G. (1995). Contributions of upper limb segment rotations during the power serve in tennis. *Journal of Applied Biomechanics, 11(4), 433-442.*

Elliott B, Reid M, Crespo M. *Technique Development in Tennis Stroke Production*. London: ITF; 2009.

Fleisig, G., Nicholls, R., Elliott, B. & Escamilla, R. (2003). Kinematics used by world class tennis players to produce high-velocity serves. *Sports Biomechanics, 2*(1), 51-64.

Girard, O., Micallef, J., & Millet, G. (2005). Lower-Limb Activity during the Power Serve in Tennis: Effects of Performance Level. *Medicine and Science in Sports and Exercise, 37*(6), 1021-1029.

Kraemer, W., Triplett, N., Fry, A., Koziris, L., Bauer, J., Lynch, J. & Knuttgen, H. (1995). An in-depth sports medicine profile of women college tennis players. *Journal of Sport Rehabilitation, 4,* 79-98.

Leversen, J., Haga, M, & Sigmundsson, H. (2012). From children to adults: Motor performance across the life-span. *PLoS ONE, 7*(6), e38830.

Lloyd, D., Alderson, J. & Elliott, B. (2000). An upper limb kinematic model for the examination of cricket bowling: a case study of Mutiah Muralitharan. *Journal of Sports Sciences, 18*(12), 975-982.

Lopez de Subijana, C & Navarro, E. (2006). The kinematic chain performed by high performance tennis players. XXIV International Symposium on Biomechanics in Sports, eds, H. Schwameder et al., Salzburg, 367-370.

Roetert, E. P., Brown, S., Piorkowski, P., & Woods, R. (1996). Fitness comparisons among three different level of elite tennis players. *Journal of Strength and Conditioning Research, 10*(3), 139-143.

Reid, M., Elliott, B. & Alderson, J. (2007). Shoulder joint loading in the high performance flat and kick tennis serves. *British Journal of Sports Medicine, 41*(12): 884-889.

Reid, M., Elliott, B., & Alderson, J. (2008). Lower-limb coordination and shoulder joint mechanics in the tennis serve. *Medicine & Science in Sports & Exercise, 40*(2), 308-315.

Reid M, Whiteside D, & Elliott B. (2011). Serving to different locations: Set-up, toss, and racket kinematics of the professional tennis serve. *Sports Biomechanics,* 10(4), 407-414.

Reid, M., Campbell, A. & Elliott, B. (2012a). Comparison of endpoint data treatment methods for estimation of kinematics and kinetics near impact during the tennis serve. *Journal of Applied Biomechanics, 28*(1), 93-98.

Reid M, Whiteside D, Giblin G, Elliott B. (2012b). Effect of a common task constraint on the body, racket, and ball kinematics of the elite junior tennis serve. *Sports Biomechanics.* ;iFirst edition; DOI:10.1080/14763141.2012.724702.

Sakurai S, Reid M, & Elliott B. (2012). Ball spin in the tennis serve: Spin rate and axis of rotation.*Sports Biomechanics* .iFirstedition; OI:10.1080/14763141.2012.671355.

Seeley M, Uhl T, McCrory J, McGinn P, Kibler B.& Shapiro R. (2008). A comparison of muscle activations during traditional and abbreviated tennis serves. *Sports Biomechanics,* 7(2), 248-259.

Sweeney M, Reid M, & Elliott B. (2012). Lower limb and trunk function in the high performance tennis serve. *Asian Journal of Exercise and Sport Science,*9(1),13-10.

Tanabe, S. & Ito A. (2007). A three-dimensional analysis of the contributions of upper limb joint movements to horizontal racket head velocity at ball impact during tennis serving. *Sports Biomechanics, 6*(3), 418-433.

Woltring, H. (1986). A fortran package for generalized, cross-validatory spline smoothing and differentiation. *Advanced Engineering Software, 8*(2), 104-107.

WTA. (2012).Tournament Calendar Retrieved Nov. 2011, from http://www.wtatennis.com/page/Calendar/.