South African Journal for Research in Sport, Physical Education and Recreation, 2016, 38(2): 17 - 25.
Suid-Afrikaanse Tydskrif vir Navorsing in Sport, Liggaamlike Opvoedkunde en Ontspanning, 2016, 38(2): 17 - 25.
ISBN: 0379-9069

UPPER EXTREMITY KINEMATICS OF FLAT SERVE IN TENNIS

Bergun M. BINGUL[1], Mensure AYDIN[1], Cigdem BULGAN[2], Ertugrul GELEN[3] & Aydin OZBEK[4]

[1] *School of Physical Education and Sport, Kocaeli University, Kocaeli, Turkey*
[2] *School of Physical Education and Sport, Halic University, Istanbul, Turkey*
[3] *School of Physical Education and Sport, Sakarya University, Kocaeli, Turkey*
[4] *Faculty of Medicine, Department of Anatomy, Kocaeli University, Kocaeli, Turkey*

ABSTRACT

The purpose of the present study was to examine of the effects of upper body kinematics on the ball velocity at the impact phase of a tennis flat serve. 15 elite male tennis players were recruited to participate in this study (mean age 18.4±3.3 years, mean height 182.3±5.6cm, mean weight 72.2±7.9kg), of which five were from the Turkish National Team. Players performed flat tennis serves on a regulation indoor tennis court. Data were recorded digitally to computer hard drives on court using three Basler A602f cameras at 100Hz. The Radar gun (Sports Radar, Astro Products, CA), was used for velocity measurements of the tennis balls. The Spearman Rank Correlation procedure was used to determine the relationships between parameters and balls. Relationships between elbow angular velocity and trunk angular velocity, as well as between elbow angular velocity and wrist angular velocity were found. The ground reaction forces transmitted through the legs and trunk allowed for greater angular velocity of the elbow, which in turn provided a favourable advantage by affecting the wrist speed and ultimately, the ball speed.

Key words: Tennis; Flat serve; Biomechanics; Kinematic analysis.

INTRODUCTION

The tennis serve is one of the most difficult of all techniques even though apparently its control and progression is fully manageable by the player. It is difficult to learn the most correct technique in view of the fact that the upper and lower extremity movements involved, require complex coordination (Bahamonde, 2000). Accordingly, the tennis serve is both the most important and the most difficult stroke to master and comes in three basic types, flat, topspin and slice (Elliott *et al.*, 1997). The flat kick (topspin), and slice (sidespin) serves employ similar upper body temporal and kinematic characteristics to produce large translational ball velocities (Sheets *et al.*, 2011). The flat serve is potentially the fastest, while the topspin serve is usually the most consistent. While velocity generation is critical to flat serve performance, the confines and dimensions of the service box necessitates the preservation of an accuracy component (Whiteside *et al.*, 2014).

Serving at high velocity in tennis generally brings a great advantage (Chow *et al.*, 2003). Biomechanical research has helped to decipher the critical kinetic and kinematic contributors to racquet velocity in the first serve and many studies have been conducted to understand these kinematics (Elliott *et al.*, 1995; Bahamonde, 2000; Marshall & Elliott, 2000; Fleisig *et al*., 2003; Tanabe & Ito, 2007). The important key factors of a serve are the racquet speed and its direction, height of the ball at stroke, weight of the racquet, the angle of the racquet at impact and the ball speed and its direction at this time.

PURPOSE OF STUDY

The serve is a sequence of motions referred to as a kinetic chain that begins with lower limb action and followed by rotations of the trunk and upper limb. This kinetic chain involves transfer of linear and angular momentum from the legs to the trunk and then to the arm and the racquet (Martin *et al*., 2012). Trunk rotation, lower limb movements and the upper limb segment rotation play an important role in the development of these critical factors (Elliott *et al*., 1997). The purpose of the present study was to examine the effects of upper body kinematics on the ball velocity at the impact phase of the flat serve.

METHODOLOGY

Ethical approval

This study was approved by the Human Ethics Committee, University of Marmara (MU) (MAR-YC-2004-0030) and was conducted in a manner consistent with the recommendations of the declaration of Helsinki.

Participants

Fifteen (N=15) elite male tennis players (mean age 18.4±3.3 years; mean height 182.3±5.6cm; mean weight 72.2±7.9kg), of whom 5 were from the Turkish National Team, were recruited to participate. All participants had at least 8 years of experience at both national and international tournaments. They completed approximately 25 hours of training per week during the period in which measurements were conducted.

Procedures

Each subject arrived at the tennis court for the testing sessions after refraining from any formal exercise, alcohol or caffeine for 24 hours. They could consume a light meal of their choice that was advised by the researchers to include complex carbohydrates, a small amount of fat and protein and water 2 to 3 hours before test.

After an appropriate warm-up, players performed flat tennis serves on a regulation indoor tennis court. At least 5 maximal official serve trials were performed. Data were recorded digitally to computer hard drives on court using 3 Basler A602f cameras at 100 Hz. In addition, a radar gun (Sports Radar 3600, Astro Products, Ontario, CA, USA) was used for velocity measurements of the tennis ball. The accuracy of the radar was 0.1km/h (0.03m/s) for a field of 10 degrees wide. It means, the accuracy of processing the speed estimate is typically 2% of the actual ball speed for SR3600 (Gelen *et al.*, 2012).

The radar gun was placed at the opposite end at the baseline. All serves, from right-handed players were directed to the left service box, while all serves from left-handed players were directed to the right service box. The best of the 5 service tries were recorded in (km/h) as the max serve (Vmax) in this analysis. For performance recordings, 1 of the cameras was placed behind the player at approximately 45° and the other 2 cameras at the opposite side of the player, positioned approximately 120° relative to each other.

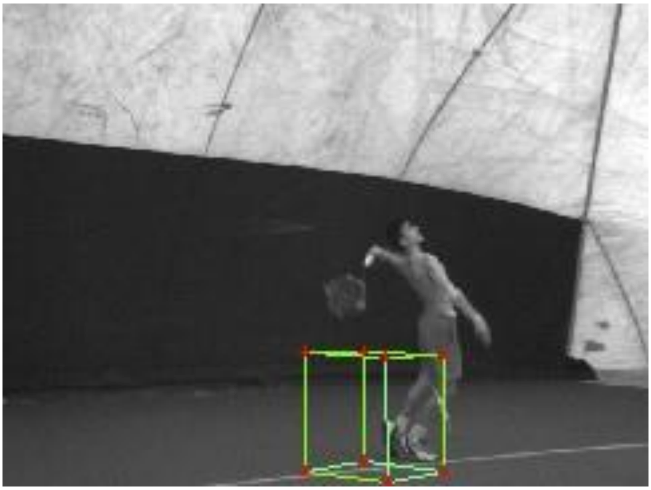

Figure 1. **CALIBRATION CUBE**

For field calibration, a Direct Linear Transformation technique, developed by Abdel-Aziz and Karara (1971) and Shapiro (1978), was used. Four calibration points were calculated by using 70cmx70cmx80cm calibration cube (Figure 1). Reflective markers were used for determining the anatomical points on body segments and the reference points on the racquet. These reflective markers were placed on the player's acromion, supra-iliac, the olecranon, processus styleoideus, and at the caput phalange V point (Figure 2).

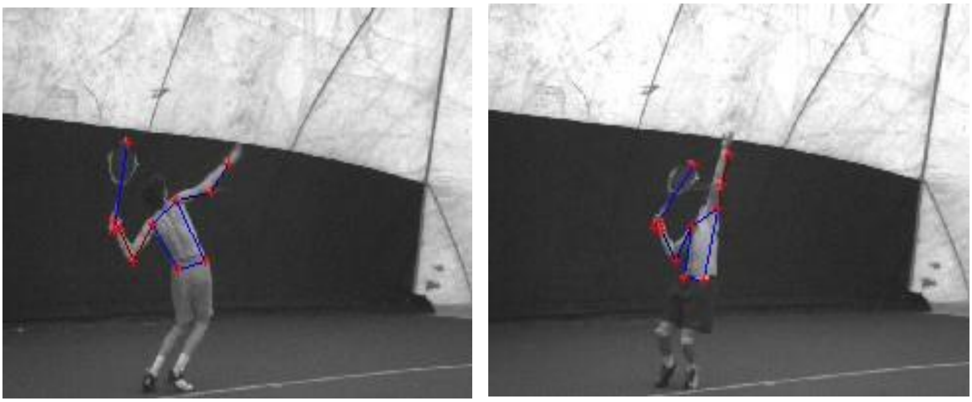

Figure 2. **MARKER POSITIONS**

The elbow angle was measured by combining the acromion, olecranon and processus styleoideus points. The shoulder angle was measured by combining the olecranon, the acromion and spina-iliaca anterior superior points. The wrist angle was measured by combining the caput phalange V, processus styleoideus points and the olecranon points. The body angle was measured by combining both the right and left spina-iliaca anterior superior and the acromion points (Figure 3).

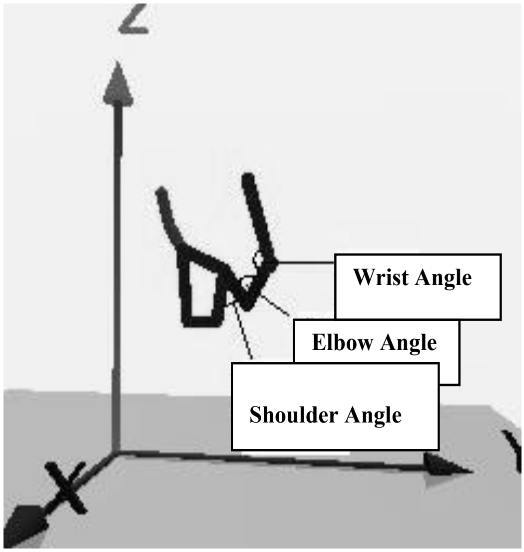

Figure 3. **JOINT ANGLES**

The serve that the radar detected at the highest velocity were analysed by using a Motion Analysis Software (Reality Motion System version 6.2, SIMI GmbH). The flat serve technique for each player was analysed by assessing the phase of the stroke determined as 5 frames before the ball leaves the racquet. The shoulder, elbow, wrist and body angular displacement were calculated in degrees (º), angular velocity in degrees/seconds (°/s) and angular acceleration values in degrees/seconds² ($°/s^2$) for the stroke phase.

Statistical analysis

All statistics were computed by using SPSS 11.5 (SPSS Inc., Chicago, IL) programme. Means and standard deviations were calculated for all variables. Spearman correlation coefficients were used to evaluate the relationships between the ball velocity and kinematic parameters (joint angles, velocities and accelerations). The level of significance was established at $p<0.05$.

RESULTS

The mean and standard deviation of shoulder, elbow, wrist, trunk angles, angular velocity and angular accelerations, as well as ball velocity parameters are summarised in Table 1.

Table 1. **UPPER EXTREMITY ANGULAR KINEMATIC PARAMETERS**

Kinematic parameters	**Mean±SD**
Shoulder angle (°)	104.74±8.79
Shoulder velocity (°/s)	-10.37±141.58
Shoulder acceleration (°/s^2)	-3104.58±918.19
Elbow angle (°)	140.24±7.42
Elbow velocity (°/s)	557.02±233.09
Elbow acceleration (°/s^2)	-18409.97±347.18
Wrist angle (°)	151.34±18.05
Wrist velocity (°/s)	105.45±363.61
Wrist acceleration (°/s^2)	3380.44±308.88
Trunk angle (°)	151.47±8.09
Trunk velocity (°/s)	-47.34±153.18
Trunk acceleration (°/s^2)	1392.88±311.99
Ball velocity (km/hr)	126.93±17.19

The relationship between the elbow angular velocity and trunk velocity about the transverse axis is presented in Table 2.

Table 2. **PEARSON CORRELATION BETWEEN PARAMETERS**

Parameters	**r**	**p**
Elbow angular velocity – Trunk velocity	0.546	0.03*
Elbow angular velocity – Wrist velocity	0.579	0.02*
Elbow angular velocity – Ball velocity	0.550	0.03*

*p<0.05

Significant correlations were found between elbow angular velocity and trunk velocity (r=0.546, p=0.03), between elbow angular velocity and wrist velocity (r=0.579, p=0.02) and between elbow angular velocity and ball velocity (r=0.550, p=0.03). However, there was no significant relationship between the ball velocity and the other kinematic parameters (p>0.05).

DISCUSSION

In tennis, the serve is one of the most important components of performance for scoring points. Because of this importance, a number of investigations have been conducted regarding the specific biomechanics of the tennis serve (Shim *et al*., 2006; Abrams *et al*., 2011; Sheets *et al*., 2011; Abrams *et al*., 2014; Whiteside *et al*., 2014).

In previous studies carried out on the tennis flat serve, the whole arm movement has been determined to be similar to the upper arm movement. The only difference between the techniques was found where the upper limb was at a different position (Lees, 2003). However, in later studies examining the tennis serve, the findings reported by Leeds (2003) were found to be wrong (Bahamonde, 2005). Elliott *et al*. (1995) determined that 90% of the linear velocity of the ball at stroke was because of the upper limb movement. In the current study, the upper extremity kinematics were analysed by considering this percentage.

Ball velocity

The ability to serve at high speed brings great advantages to the player (Chow *et al*., 2003). Elliott *et al*. (2003) determined the serve speed for male players to be 182.8km/h. In a more recent study by Sun *et al*. (2012), the ball serve velocity was recorded as 157.92km/h (42.64m/s). In the present study, the average velocity attained by the players was 126.93km/h. Although two of the players performed a serve velocity of 150km/h, the general speed results of the players in this study were slower than that reported in the literature. However, their movements were important in the study based on the effects of strike techniques on the speed of the ball.

Relationships between upper body angular velocity and ball velocity

Based on the statistical analysis, a significant relationship was found between ball velocity and the angular velocity of the elbow ($r=0.550$, $p<0.05$). The angular velocity of the elbow was 557.02±233.09°/sec. Due to the statistically significant relationship between trunk and elbow angular velocity, it may be inferred that trunk rotational angular momentum may contribute to increased elbow angular velocity. The elbow extension was the second greatest contributor to racquet speed at impact (Abrams *et al*., 2014). Although the present study did not find a significant correlation between trunk and ball velocities, other studies, such as that of Bahamonde and Knudson (1998), did find a significant correlation between these two variables.

Martin *et al*. (2012) found a relationship between maximal trunk angular momentum about the transverse axis and ball velocity in their study. The angular momentum created during the serve corresponds to a three-lever system comprising the trunk, the arm and the racquet (Bahamonde, 2000). Martin *et al*. (2012) indicated that between maximal external rotation of the shoulder joint and impact, the trunk lost most of its forward angular momentum and in contrast, the arm holding the racquet gained most of its forward angular momentum during the same stage of the serve.

Relationships between upper body angles and ball velocity

Buckley and Kerwin (1988) in their study recorded the elbow extension angular velocity as 27.8±4.1rad/s and the elbow extension angle as 115.8°±9.6° just before hitting the ball.

Bahamonde (2005) reported that the elbow is not completely extended at stroke and the angle remains between 154 to 164°. In the present study, the average elbow angle was found to be 140.24°±7.42° indicating that the angle was less than findings reported in the literature. In any case, the low-ball velocity could be related to the decreased elbow angle considering that the velocity of the ball is affected by the elbow angle, as determined to be the only factor influencing velocity. The increase in the elbow extension angle would be advantageous in attaining higher levels of velocity.

Kinematic chain

During the power serve, a number of body segments must be coordinated in a sequence referred to as the "kinematic chain" (Kibler & Van der Meer, 2001), to produce optimal racquet position, trajectory and velocity upon impact with the ball. It begins with the lower limb action and then followed by rotations of the trunk and upper limb (Martin *et al*., 2012). Putnam (1993, cited in Abrams, 2014), reported that the proximal muscles of the scapula and trunk are mostly responsible for absorbing the forces generated earlier in the chain.

This chain involves a transfer of linear and angular momentum from the legs to the trunk and then to the arm and the racquet (Bahamonde, 2000). According to Bahamonde (2005), the tennis serve requires a coordinated transfer of momentum from proximal to distal segments in sequence and found the maximal extension angular velocity (of the elbow) to be approximately 1.230–2.527°/s in his study. In the present study, a significant positive correlation was found between the angular velocity of the wrist and the elbow angular velocity ($r=0.571$, $p<0.05$), which demonstrates the progressive movement from proximal to distal. Martin *et al*. (2012) found that the players with the highest values for upper body segmental angular momentum about the transverse axis are those with the highest ball velocity. The most important findings of their study were the significant correlations between mean trunk angular momentum and ball velocity values.

PRACTICAL APPLICATION

The tennis serve can be enhanced by performing the serve correctly and making use of the kinematic chain where forces may be transferred from the ground to the upper extremities. It is very effective to continue transmission correctly in the form of this chain (linear displacement, rotations, etc.), in the upper extremity. Coaches and teachers will be able to enhance the ball speed the tennis players attain by emphasising trunk rotation and implementing training programmes that improve the rotational velocity of the kinematic chain.

CONCLUSION

It can be concluded that the optimal body rotation is an important factor with regard to enhancing the whole body angular momentum and in turn transferring this from the elbow to the wrist, thereby ultimately leading to enhanced ball velocity at impact.

REFERENCES

BAHAMONDE, R.E. (2000). Changes in angular momentum during the tennis serve. *Journal of Sports Sciences*, 18(8): 579-592.

BAHAMONDE, R.E. (2005). Review of the biomechanical function of the elbow joint during tennis strokes. *Journal of International Sport Medicine*, 6(2): 42-63.

BAHAMONDE, R.E. & KNUDSON, D. (1998). Kinematic analysis of open and square stance tennis forehand. *Medicine and Science in Sports and Exercise*, 30(5): 5-29.

BAHAMONDE, R.E. & KNUDSON, D. (2003). Kinetics of the upper extremity in the open and square stance tennis forehand. *Journal of Science and Medicine in Sports*, 6(1): 88-101.

BUCKLEY, J.P. & KERWIN, D.G. (1988). The role of the biceps and triceps brachii during tennis serving. *Ergonomics*, 31(11): 1621-1629.

CHOW, J.W.; CARLTON, L.G.; LIM, Y.T.; CHAE, W.S.; SHIM, J.S.; KUENSTER, A.F. & KOKUBUN, K. (2003). Comparing the pre- and post-impact ball and racquet kinematics of elite tennis players' first and second serves: A preliminary study. *Journal of Sports Science*, 21(7): 529-537.

ELLIOTT, B.C.; FLEISIG, G.; NICHOLLS, R. & ESCAMILLA, R. (2003). Technique effects on upper-limb loading in the tennis serve. *Journal of Science and Medicine in Sport*, 6(1): 76-87.

ELLIOTT, B.C.; MARSHALL, R.N. & NOFFAL, G.J. (1995). Contributions of upper limb segment rotations during the power serve in tennis. *Journal of Applied Biomechanics*, 11(4): 433-442.

ELLIOTT, B.; TAKAHASHI, K. & NOFFAL, G. (1997). The influence of grip position on upper-limb contributions to racquet heat velocity in a tennis forehand. *Journal of Applied Biomechanics*, 13(2): 182-196.

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.

GELEN, E.; DEDE, M.; BINGUL, B.M.; BULGAN, C. & AYDIN, M. (2012). Acute effects of static stretching, dynamic exercises and high volume upper extremity plyometric activity on tennis serve performance. *Journal of Sports Science and Medicine*, 11(4): 600-605.

KIBLER, B. & VAN DER MEER, D. (2001). Mastering the kinetic chain. In P. Roetert & J.L. Groppel (Eds.), *World-class tennis technique: Master every stroke* (pp.99-113). Champaign, IL: Human Kinetics.

LEES, A. (2003). Science and the major racket sports: A review. *Journal of Sports Sciences*, 21(9): 707-732.

MARTIN, C.; BIDEAU, B.; NICOLAS, G.; DELAMARCHE, P. & KULPA, R. (2012). How does the tennis serve technique influence the serve-and-volley? *Journal of Sports Sciences*, 30(11): 1149-1156.

SHAPIRO, R. (1978). Direct linear transformation method for three-dimensional cinematography. *Research Quarterly*, 49(2): 197-205.

SHEETS, A.; ABRAMS, G.D.; CORAZZA, S.; SAFRAN, M.R. & ANDRIACCHI, T.P. (2011). Kinematics differences between the flat, kick and slice serves measured using a marker less motion capture method. *Annals of Biomedical Engineering*, 39(12): 3011-3020.

SHIM, J.; CARLTON, L.G. & KWON, Y. (2006). Perception of kinematic characteristics of tennis strokes for anticipating stroke type and direction. *Research Quarterly for Exercise and Sport*, 77(3): 326-339.

SUN, Y.; LIU, Y. & ZHOU, X. (2012). Kinematic analysis of a top 10 WTA tennis players' first serve. In E. Bradshaw & A. Burnett (Eds.), *Scientific Proceedings of 30^th Annual Conference of Biomechanics in Sports* (27 June to 1 July) (pp.253-255). Melbourne, Australia: Australian Catholic University, International Society of Biomechanics in Sports.

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.

WHITESIDE, D.; ELLIOTT, B.; LAY, B. & REID, M. (2014). The effect of racquet swing weight on serve kinematics in elite adolescent female tennis players. *Journal of Science and Medicine in Sport*, 17(1): 124-128.

Prof Bergun Meric BINGUL: The School of Physical Education and Sport, Kocaeli University, Umuttepe, Kocaeli, TURKEY. Tel.: +902623033602, Fax.: +902623033603, Email: bergunmeric@gmail.com

(Subject Editor: Mr Mark Kramer)