KINEMATICS OF THE HAND AND KEY ROTATION IN A TENNIS FOREHAND DRIVE OF TENNIS PLAYERS

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The purpose of the present study was to quantify kinematic variables of the hand of dominant arm and the main responsible rotation of the upper limb to the racket head velocity in an attack tennis forehand drive. Three elite tennis players and three high-performance tennis players were recorded with inertial measurement units (IMUs) with a frequency of 120 Hz during a cross-court (CC) and an inside-out (IO) forehand drive. The six fastest strokes in both directions were selected for analyses. Differences between two directions were shown in the follow through with a higher wrist abduction when playing in the inside-out direction (cross-court: 13.9 ± 17.2°; inside-out: 16.9 ± 18.6°). Results demonstrated that the horizontal flexion of the upper arm were the main responsible for the racket head velocity (48.1% CC and 45.2% IO).

KEY WORDS: forehand kinematics, inertial sensors, racket velocity.

INTRODUCTION: In tennis the forehand drive is usually linked to a great amount of points won by the player (Cam, Turhan, & Onag, 2013) and, it is considered the second most important stroke in tennis after the serve where the velocity of the racket is an key goal to achieve a higher performance (Landlinger, Lindinger, Stöggl, Wagner, & Müller, 2010a). For this reason kinematic knowledge, present a determinant factor to develop high performance forehand strokes and present a great importance to reduce the threat of injuries that affect tennis players (Elliott, 2006). Kinematic description in the forehand tennis stroke were mostly developed with high-speed video cameras using a reflective marker set up (Elliott, Marsh, & Overheu, 1989; Landlinger, Lindinger, Stöggl, Wagner, & Müller, 2010b; Nesbit, Serrano, & Elzinga, 2008; Seeley, Funk, Denning, Hager, & Hopkins, 2011). This methodology is usually linked to a considerable time expenditure, for that reason, IMUs present an alternative and easy system to develop kinematic sport studies. Based in recommendations of Reid, Elliott, & Crespo, (2013) IMUs present an alternative to study tennis strokes with an alternative methodology especially to describe fine movements of the hand such as radial, ulnar and palmar flexion (Rogowski, Rouffet, Lambalot, Brosseau, & Hautier, 2011). Moreover, the majority of the studies were performed with players hitting the forehand drive from the baseline, in this way we pretend to describe the kinematics of the hand in forehand stroke in an advanced position in the court, where tennis players attack the ball. In this way the aim of this study was to quantify the kinematic variables of the hand when players hit the forehand drive in the cross court-direction and inside-out direction. The second purpose of this study was to determine the most important rotation of the upper limb to the racket velocity in a tennis forehand drive using the method described by (Sprigings, E., Marshall, R., Elliot, B. and Jennings, 1994)

METHODS: Six highly skilled male tennis players (age 21 ± 4 years, height 178.17 ± 2.9 cm, mass 73 ± 1.8 Kg) volunteered to participate in the study. At the time of data collection, three players presented ATP ranking ranged between 630 and 1520 and others three players presented a national ranking ranged between 4 and 69 and, five of them used a semi-western grip and one a western grip. Informed consent for the following procedure was obtained for all participants, which was approved by the Ethics Committee. Prior to data collection participants observed a demonstration of the experimental procedure and, they were permitted to familiarize with the test conditions. A ball machine projected new tennis ball with controlled velocity (24.5m/s) to a target area (Figure 1). Starting at the basely, participants were instructed to hit six series of thirteen forehands. A forehand stroke were valid when the ball landed inside the target area 1 and 2 (Figure 1) (Landlinger, Stöggl, Lindinger, Wagner, & Müller, 2012). The six fastest shots for each target were select for the present study.

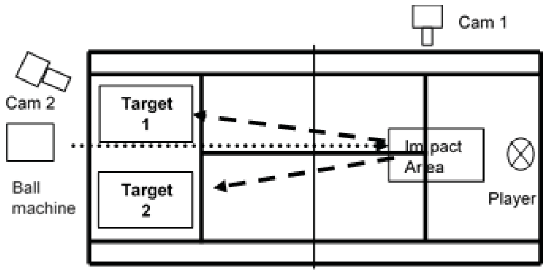

Figure 1 - Testing enviroment.

A portable IMUs using 17 sensors on the head, scapulae, upper arms, forearms, hands, sternum, pelvis, thighs, shanks and feet, during forehand strokes. Through the integration of gyroscopes and accelerometers signals the inertial measurement system estimates the position and orientation of each body segment (Roetenberg, Luinge, & Slycke, 2009).To express each segment kinematics in the global frame each subject performed several calibration steps to orientate the sensor with the respective segment and to determine the relative distances between joints (Roetenberg et al., 2009). The global reference coordinate system used is defined as a right-handed Cartesian coordinate system with: positive X-axis pointing to the local magnetic North; Y-axis positive in accordance with the right hand coordinates (West) and Z-axis positive when pointing up. The local reference coordinate system also uses the right hand Cartesian coordinate system with: X-axis pointing forward, Y-axis pointing up, from joint to joint and Z-axis pointing right. A video camera Qualisys (model: Oquos 210c) operating at 240Hz were synchronized with inertial system to determine the ball contact. Kinematic data collected by the MVN Studio Pro software were exported in C3D format and analysed with the Visual 3D software (Visual 3D Professional V5.01.21, C-motion, Germantown, MD) and used to the reconstruction of the fifteen body segments. These reconstructed segments were developed with imported length and local coordinate system. Joint angles of the dominant arm were calculated using an Z-Y-Z cardan rotation sequence for shoulder rotations (Seeley et al., 2011) and a X-Y-Z cardan rotation sequence for the others joint angles.The placement of the shot was verified by a video camera that was placed above the tennis court. To determine the most important upper limb rotattion to the racket head velocity it was used the method described by Sprigings, Marshall, Elliot and Jennings (1994) with MATLAB software (R2010A). All statistical analyses were performed using SPSS version 20 (SPSS Inc. Company, Chicago). Means and standard deviation of the variables were calculated for the descriptive statistics. For each parameter, data from cross court and inside out direction a Wilcoxon Matched-Pairs Signed Ranks test were used to test for significances differences between two directions. The level of significance was set at $p \leq 0.05$.

RESULTS: Table 1 displays the means and standard deviations of the joint angles of the upper-arm during the end of the backswing, impact, follow through (end of forward racket movement) and peak joint angles between the end of the backswing and the ball impact in two directions (CC and IO). Abduction of the wrist at the end of the follow through have demonstrated significant differences between the two directions, showing a higher abduction of the wrist in the inside out direction ($p<0.05$) (Table1). At the impact, the linear velocities of the center of the racket head in the horizontal direction were 21.8 ± 2.2 m/s in the cross-court and 22.6 ± 1.8m/s in the inside out direction (Table 1). Results of this study revealed that the most important contribution for the racket head velocity is the flexion/abduction of upper arm: 48.1% (CC) and 45.2% (IO). Results did not demonstrated significant differences in the contributions in two directions of the shot.

Table 1 – Means and standard deviation for hand joint angles in end of backswing, impact, follow through and peak joint angles form the ecelleration instant to impact. Contribuition for racket head velocity and velocity of the center of the racket.

Angular Displacement	Cross-Court (M±SD)	Inside-Out (M±SD)
Wrist Flexion (+) / Extension (-)		
End of backswing (°)	-18.4 ± 13.6	-19.0 ± 14.2
Impact (°)	-30.4 ± 13.3	-31.3 ± 12.7
Follow through (°)	-22.9 ± 14.1	-18. 9 ± 13.7
Peak (°)	-52.1 ± 11.1	-52.6 ± 11.1
Wrist adduction (-) / abduction (+)		
End of backswing (°)	4.8 ± 13.7	5.8 ± 13.1
Impact (°)	1.8 ± 18.2	1.2 ± 18.2
Follow through (°)	13.9 ± 17.2^{+}	16.9 ±
Contribution for Racket Velocity		
Flexion/Extension /Adduction/Abduction		
M (±SD) (m/s)	10.4±4.6	10.0±3.4
Contribution (%)	48.1	45.2
Center of racket		
M(±SD) (m/s)	21.8±2.2	22.6±1.8

DISCUSSION: The aim of the present study was to quantify the kinematic variables of the hand and the most important contributions of the upper limb segment rotation to the racket head velocity in the cross-court and inside-out forehand. Results demonstrate that the rotations of the hand, specially the abduction and adduction could be related to the directions of the shot. On the other hand, results demonstrated that the most important rotation of the upper limb to the racket head velocity was the horizontal flexion of the upper limb. During aceleration phase the wrist extension we can observe the same pattern described by (Elliott, 1990), which in the beginning of the forward swing, the right wrist starts to increase the extension angle and flexes just before the impact, maintaining however the wrist in extension at impact. It was demonstrated that the flexion of the wrist just before the impact is accompanied by the abduction of the wrist, helping to increase the velocity of the racket at impact. This reported data could add knowledge to the work of Isabelle Rogowski et al., (2011) who referred the need for new biomechanical models to describe fine movements such radial, ulnar and palmar flexion. On the other hand, Seeley et al., (2011), reported an association of the wrist extension before the impact with the increase of ball velocity, although, in this study we observed a lower wrist peak extension angle before impact despite the shot studied were a powerful forehand. Landlinger et al., (2010a) also reported a higher peak angular displacement in the wrist (CC: -89.6 ± 11.3° vs. (DL): -87.7 ± 10.0°). When comparing the most important contribution with the findings of Elliott et al., (1997) we realize some differences where they reported the internal rotation of the upper arm as the most important rotation for the forehand drive. Naturally, these differences could be related with the grip used by, level of players or local of impact. As reported by Elliot et al., (2005) where the internal rotation of the upper arm is the main responsible for the racket velocity in serve and despite in this study this rotation were not shown as the most important, players should be careful by making work to prevent injuries especially in the external rotators (Elliott, 2006). Velocity of center of the racket in this study was a superior than reported by Elliott et al. (1997) when comparing with the group who hit a flat forehand with 17.0m/s in players who hit the ball with an eastern grip and 16.8m/s in the group who hit the ball with an western grip. On the other hand Landlinger et al., (2010b) presented a higher velocity of the racket (33.1m/s) in elite tennis players, although different methods were used.

CONCLUSIONS: We can considered that the IMU's systems present a useful system to study fine movements of upper arm rotations and the. Despite no great differences, we have find kinematics differences of the hand between the two directions of the shot. We can speculate that the signicant differences in the abduction/adduction of the hand in the follow through could be associated to the direction of the shot. In this way, we find important to continue to study these fine rotations in order to understand and confirm these results. In relation to the contributions for the racket head velocity, it is also necessary to develop more studies to confirm the results of this study. The findings of this study could present a framework for tennis coaches to help players developing their forehand strokes. One limitation of this study is the fact that players with different grips were not divided, which could present a limitation in the results.

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