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**Research Article**

## KINETIC ENERGY TRANSFER DURING THE SERVE

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## ABSTRACT

Several studies have established the pattern used in the over arm hitting and throwing movements, however to date there has not been one which statistically expresses the Kinetic Link Principle of the tennis serve. The main goals of this study were: first to investigate the kinetic energy transmission pattern using a complete mechanical body model and second, to create a tool which could help evaluating the individual technique of a tennis player. This tool was a statistical procedure which expressed the individual technique of a player as a mathematical function. Fourteen and twelve flat tennis serves of two top tennis players landing in an aiming area were recorded with two synchronized video cameras at 125 Hz. The experimental technique was 3D photogrammetry. A 28 points body model with five solid-rigid (the pelvis, the thorax, the upper arms and the racquet) was built. The kinetic energies from the body segments were considered the biomechanical parameters. The mean speeds of the balls were 41.9 m/s and 38.1 m/s. A Kinetic Sequential Action Muscle principle based on the kinetic energy transfer was probed statistically by mean a correlation analysis. This pattern showed the existence of a proximal to distal sequence of kinetic energy maximums. A significant ($p<0,05$) discriminant function for each player could predict the category of the serve ("good" or "bad") in the 78,6 % and 100 % of the cases. This function facilitated the understanding of the individual technique of a tennis player showing that this could be a tool for the tennis training complementary to the qualitative (observational) analysis.

***Key words:*** *Biomechanics, tennis, hitting*

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## INTRODUCTION

The tennis serve is one of the fundamental strokes during the development of a match and could be a key factor determining its outcome (Elliott, Marsh, & Blanksby, 1986). It is also one of the most difficult strokes to execute as the act of throwing the ball and then hitting it on its downward flight, requires a complex multisegment co-ordination between the ball, the hitting body segments, the trunk and the lower limbs, (Bahamonde, 2000). It is the only shot in tennis where the player depends solely on himself (closed feedback task).

As a throwing and hitting pattern, the tennis serve is a sport skill classified as an over arm pattern (Kreighbaum & Barthels, 1981) where its main goal is to achieve an appropriate trajectory and optimal speed of the racquet at impact. The speed of the tennis serve from top players has been increasing reaching 69.3 m/s from Andy Roddick in the 2004 season, (ITF, 2004). High velocities in the tennis serve guarantees more winning points, and if this successful first serve is combined with a good percentage, the probability of winning the match increases considerably (Brody, 2003).

Haake, Rose, & Kotze (2000) showed that when the speed of the tennis serves is over 45 m/s the number of errors at the return increases significantly. Previous studies registered at tennis serves were under 30 m/s (27 and 28.83 m/s) (Sprigings, Marshall, Elliott, & Jennings, 1994 and Ito, Tanabe, & Fuchimoto, 1995); except by Elliott, Marsh, & Blanksby (1986) which reported 34.4 m/s in females and 42.2 m/s in males.

The kinetic chain is based on the “kinetic link principle” where the generation of high end-point velocity accomplish with the use of accelerating and decelerating of adjoining links. Therefore, the segments reach its maximum of speed consecutively beginning for those farthest of the kinetic chain free end (Kreighbaum & Barthels, 1981). The Kinetic Energy is composed by a linear component which accounts the linear velocity of a segment and by a rotational component which considers the angular velocity of the segment. There are no studies of the tennis serve which use the kinetic energy as the main biomechanical parameter.

Some authors have described the kinetic chain at the tennis serve based on the angular velocities at the lower limbs, trunk and raquet-arm (Elliott, 2002; Fleisig et al., 2003) and which one of them where the mayor contributors (Gordon & Dapena, 2006). Reid, Elliott, & Alderson (2008) showed the importance of the knees extension and the angular velocity of the rear knee at the two common techniques at the tennis serve: the “foot up” and the “foot back”.

None of the previous studies analysed the “kinetic link principle” in the way as how the deceleration of one segment influences the acceleration of the next one in the kinetic chain. Analysing the kinetic energy transfer from one segment to another until impact could provide greater understanding of the tennis service mechanics. In order to study the transmission of energy between segments, a mechanical model that considers the segments as solid rigid (six degrees of freedom) and that takes into account both the linear and rotational energy is required.

Coaches are frequently faced with the task of observing movement and then offering feedback about the improvement of technique (Barlett, 1999). To be successful, this process requires a model against which a comparison can be done. Also, objective procedures of evaluating the technique are needed by the coaches in order they can give a good feedback to their athletes. Some authors have reflected the importance of the feedback at the sport skills learning processes. Being the extrinsic feedback a supplementary information fundamental for the learner (Perez et al., 2009; Viitasalo et al., 2001). The feedback is not recommended to be continuous (Lai & Shea, 1999; Schmidt & Wulf, 1997) so this biomechanical procedure is suggested to be applied during a technical session of the training period, before the competition season starts.

Consequently, the first goal of this study was to develop a mechanic body model applied to tennis, which would take into account the energy transfer between the segments and the racquet. The second goal was to develop a biomechanical tool which can be applied by coaches during the technical training process. This tool will be based on the concept that the individual characteristics of the player should be taken into account as a reference during the technical training.

## MATERIAL AND METHODS

3D photogrammetry was used to collect data from two female top tennis players ranked around 40 and 60 WTA that week. Player (A) was 1.63 m tall and had a 62.5 kg of mass while player (B) was 1.61 m tall and had a 61 kg of mass. Two digital high velocity colour video cameras KODAK MOTIONCORDER Analyser SR-500-c sampling at 125 Hz were used. One camera recorded a side view and the second one recorded frontal angle close to the tennis net. The location of the cameras changed throughout the session as one player was right-handed and the other left-handed (Figure 1). Both cameras were genlocked.

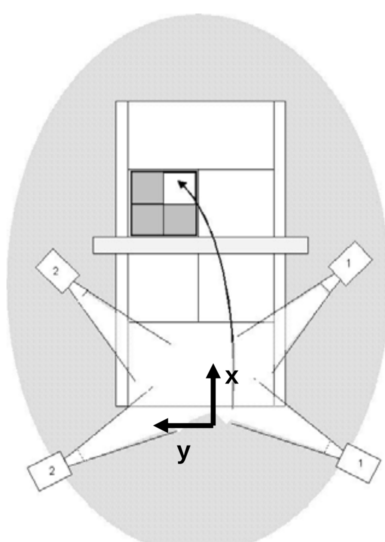


***Figure 1.*** *Camera locations and target are*

Fifteen flat tennis serves from each player which landed in an aiming area into the serve box were registered. This aiming area was a square of 2 m length (Figure 1) considered as the “natural” target area for first serves of both players. Players specifically warmed up prior data recording session. First the right handed player was recorded. Each serve was registered from the toss of the ball until the follow-through after impact. Due technical problems from all the registered serves, a total of 12 from player (A) and 14 from player (B) were analyzed.

The processing phase required digitalizing points manually of the mechanical model in each frame and also of the points which defined the calibration object. The Photo 23 D Software from the Sport Biomechanics Laboratory of the Polytechnic University of Madrid was used for digitizing. The calibration object was a pre-calibrated cube of 2 m length which comprised the space where the movement was produced and it was recorded before filming the serves (Figure 2). The error associated with the calibration was less than 1 mm The DLT, Direct Linear Transformation (Abdel-Aziz, 1971) was applied to obtain the 3D coordinates.


***Figure 2.*** *Calibration Object*

The mechanical model was adapted from Clauser, McConville, & Young (1969) and Zatsiorsky, Seluyanov, & Chugunova (1990) taking a 28 point model definition into consideration (Figure 3). Twenty three points were from the body (foot toe, ankle, heel, knee, hip, abdominal, lower sternum, sternum, gonion, vertex, shoulder, elbow, wrist and hand), 4 from the racquet (both sides at racquet head, proximal and the distal point at the racquet head), and one point for the ball. Seventeen segments were defined: 12 as bars (5 degrees of freedom) and 5 as solid-rigids (6 degrees of freedom). Head, lower arms, hands, abdomen, thighs, legs and feet were considered as bars.

The inertial reference system followed the axis of the calibration object. The X axis was from back to front, the Y axis, from right to left and the Z axis was vertical. In order to obtain the 6 degrees of freedom from the solid-rigids, fixed Local Reference System (LOC) in accordance with the anatomic axis, were determined (Figures 1,2 and 3). Local Reference Systems were defined from the coordinates (x, y, z) of three non-linear point coordinates in the segments pelvis, the thorax and the racquet. Three points at the shoulder, elbow and wrist taking the elbow as a joint of one degree of freedom (Navarro et al., 1995) were used to define the upper arms LOCs (Figure 3).

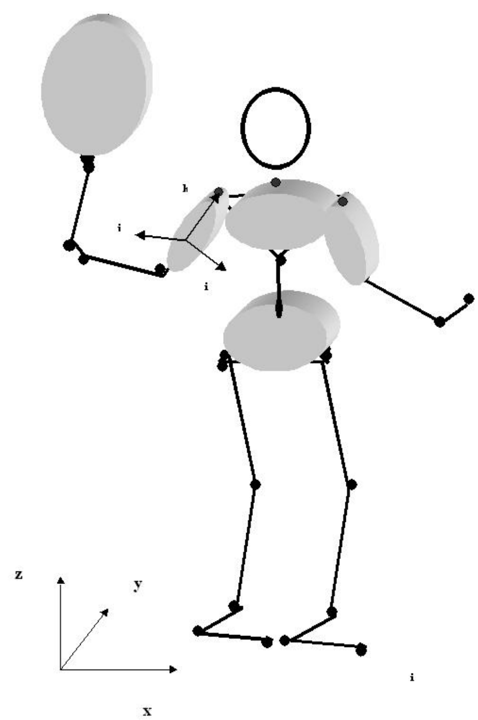

***Figure 3.*** *Model created for the right-handed player (28 points and pelvis, thorax, uppers arms and Raquet as Solid-rigids).*

The inertial parameters of the human body were taken from De Leva (1996) after measuring the weight and height of both players. The racquets were “Fischer Pro One” y “Volk Classic 7 Pro”, with dimensions, mass and “swing weight” known. The moment of inertia of the racquet about their three axis were calculated applying the parallel axis theorem (Brody, 2005) and the published racquet “swing weight” data, (USRA, 2002). The filtering and interpolation was done through 5th order spline functions (Woltring, 1985). The resulting mean error at the coordinates of a point was obtained from digitalizing 3 non-consecutive frames 30 times I was established at 0,015 m.

***Hitting Pattern Parameters***

The Ball Speed (Vb) and the Body Segments’ Kinetic Energies (Ke) were the parameters chosen for this study. The ball speed was the performance criteria established to classify the serves. The speed was estimated as the mean velocity between the last frame where the ball was in contact with the racquet strings and the next frame (1/125 s after impact). The 3D coordinates of the ball were not filtered nor smoothed as Gordon & Dapena (2006) suggested. The performance levels of the player’s serves were established as level 1 being “good” serves and level 2, “bad” serves. The median of the ball speed measured was used to classify the serves. The Kinetic Energy was taken as the sum of the Translation Kinetic Energy and the Rotation Kinetic.

***Statistical Parameters***

Normalized Parameters were defined for the statistical study. The normalized parameters expressed the increments (positive or negative) in each interval, normalized respect to the initial kinetic energy. For example the Lower Limbs Kinetic energy increase from t1 to t2, (ΔLL Ke 12n) is calculated following these steps:

1. LL Ke = (KE Left Thigh + KE Right Thigh + KE Left Tibia + KE Right Tibia + KE Left Foot + KE Left Foot + Ke Pel)

2. ΔLL KE12 = LL Ke 2 – LL Ke 1

3. Δ LL Ke 12n = ΔLL KE12 / LL Ke 1x 100

Different Groups of body segment kinetic energies were considered in each player. For player A, the body segment kinetic energy groups made were Lower Limbs (LL Ke), Trunk (Tr Ke), Upper arm (Ua Ke), Lower arm (La Ke), and Hand & Racquet (HR Ke). In the case of player B, the increasing of normalized kinetic energy was applied to these body segment groups: Lower limbs and pelvis (LL-pel Ke), thorax and upper arm (Th-ua Ke), Lower arm (La Ke) and Hand & Racquet (HR Ke).The whole serve was divided into 4 intervals defined by the group of body segments. Kinetic energy peaks. The events which determined each interval were: t1, maximum knee flexion with both feet on the ground, t2, maximum Tr Ke for player A and maximum LL-pel Ke for player B, t3 maximum Ua Ke for player A and maximum Th-ua Ke for player B, t4, maximum La Ke and t5, maximum HR Ke.

A correlation analysis between the parameters in each interval was carried out for both players in order to establish the existence of a kinetic energy transfer model. A discriminant analysis determined the hitting pattern of each player.

## RESULTS

### *Performance Criteria and Established Levels*

Player A reached a mean speed of the ball of 41.9±1.6 m/s while player B achieved 38.1±1.2 m/s. For player A the median was 41.4 m/s and for player B the median was 38.1 m/s. The significant differences of level 1 and level 2 of the tennis serves were at $p<0.05$ for player A and at $p<0.01$ for player B.

### *Kinetic Chain*

The definition of the body segment groups were based on the sequences of movements produced by each player. In a first qualitative analysis, as Knudson (2007) recommended, the players showed very different techniques. Player A had an abbreviated swing with a "foot back" technique, while player B used a full swing with a "foot up" technique. In player A both feet were maintained separate throughout the shot. At Player B the feet started separate but they gather together at the same time as knee flexion occurred. It could be seeing that player A rotated less in general than player B.

At first, it was estimated the Maximum External Rotation (MER) as a key event but after analysing the maximum kinetic energy of the upper arms, (Max Ke u-arm), the event did not take place in both players before the max Ke u-arm. In player A, MER was, (mean±sd), at -0.075±0.009 s before impact and maximum Ke u-arm was at -0.106±0.006 s. At player B MER was -0.116±0.005 s and maximum Ke u-arm was 0.098 ± 0.006 s. This meant that for player A the MER followed the maximum kinetic energy at upper arm because the external rotation was negligible. At Player B happened in a more logical sequence with first MER followed by the max Ke u-arm. This fact supported the idea that the individual technique has to be taken into account in the performance evaluation.

The evolutions of the kinetic energy throughout the shot in both players from the maximum knee flexion until some frames after impact are shown in figures 4 and 5. Player A, at the initial interval (t1-t2), started the increment of lower arm kinetic energy along with the hand and racquet, and upper arm. The trunk reached its maximum energy while the lower limbs decreased. At the t2-t3 interval, the lower limbs continued decreasing; the trunk also decreased, while the upper arm, the lower arm and the hand & racquet energy increased their energies. At the t3-t4 interval, the lower arm reached its maximum energy, while the hand and racquet increased their energy. The upper arm energy decreased at the same time as the lower limbs and the trunk. In the last interval, the hand and racquet reached its maximum values, considerably higher than the other parameters. The lower arm, the upper arm and the trunk decreased their energy while the lower limbs increased slightly as a consequence of their movements during the follow-through. For player B during the first interval t1-t2, the lower limbs and pelvis reached their maximum energy, followed the by increases on thorax and upper arm and the hand and racquet energy. At t2-t3, the hand and racquet kept increasing, the thorax and upper arm reached its maximum, and the lower limbs and pelvis began to decrease its energy. At t3-t4, the lower arm reached its maximum energy with the hand and racquet increasing, while the lower limbs and thorax and upper arm decreased their energy. At the t4-t5 interval, the hand and racquet group reached energy values significantly higher in comparison the other body segment groups. During this interval the thorax and upper arm and the lower arm lost energy.

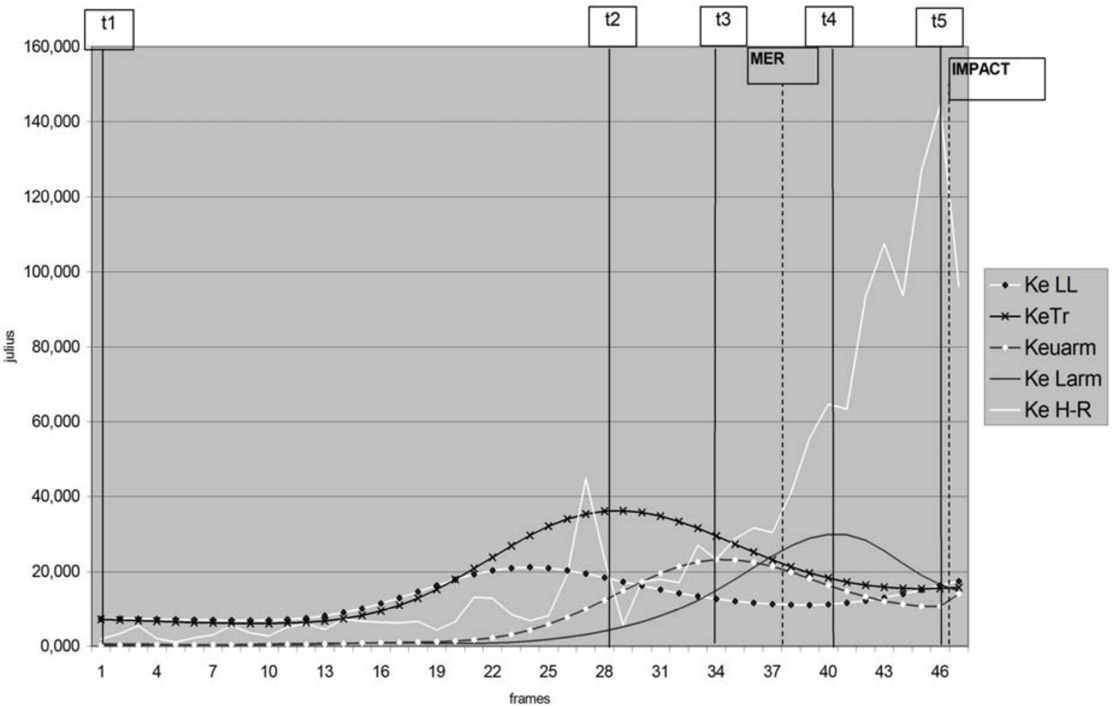


***Figure 4.*** *Kinetic Energy from A player (Where LL = lower limbs; Tr = Trunk; Uarm= upper arm; Larm= lower arm; H-R= hand and racquet)*

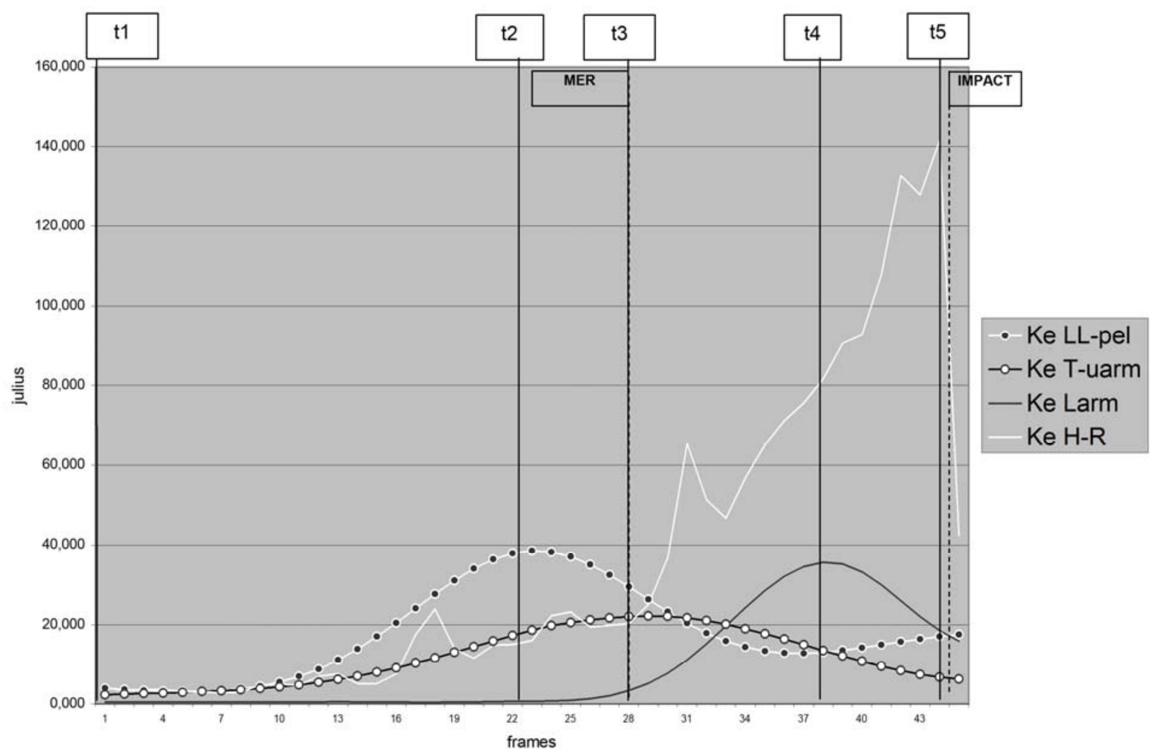


***Figure 5.*** *Kinetic Energy from B player (Where LL-pel= lower limbs and pelvis; T-uarm= thorax and upper arm; Larm= lower arm; H-R= hand and racquet).*

The correlation analyses of the parameters are shown in table 1 and 2. The significant correlations found in each interval, which divided the shot, are shown in both tables. The significant correlation found indicated a possible relationship between the increase and decrease of the body segment group energies during an interval. For player A during t1-t2, all the correlations between the parameters which increased were positive (all at $p<0.05$ but $p<0.01$ at the upper arm with the lower arm). At t2-t3, there were positive correlations between the decrease of the lower limbs and the trunk, ($p<0.05$), and between the increase of the upper arm and the lower arm ($p<0.01$). The negative correlations between the lower limbs decrease and the upper arm increase ($p<0.05$), and between the trunk and the lower arm ($p<0.05$), indicated a possible energy transfer relationship between the deceleration at the thighs and trunk, and the acceleration at the upper arm and lower arm. During the t3-t4 interval, the trunk decrease was negatively correlated with the lower arm increase ($p<0.05$). In the last interval, t4-t5, the lower limbs increase was negatively correlated with the lower arm decrease ($p<0.01$). On the other hand, the trunk and upper arm decrease were positively correlated ($p<0.05$). For player B, during the t1-t2 interval, all the parameters increased. The thorax and upper arm and the hand and racquet increases were positively correlated ($p<0.01$). At t2-t3, the increase of the thorax and upper arm and the increase of the lower arm, were negatively correlated ($p< 0.01$) with the lower limbs decrease. This could explain the energy transfer from the lower limbs to the upper and lower arm segments. However, the thorax and upper arm and lower arm increase were positively correlated ($p<0.05$). At t3-t4, all parameters were correlated, with a positive correlation between the lower arm and hand and racquet increases ($p<0.01$), and between the lower limbs and thorax and upper arm decreases ($p<0.01$). Negative correlation between the increasing parameters; lower arm ($p<0.01$) and hand and racquet ($p<0.05$ and $p<0.01$), with those which decrease, the lower limbs and upper arm energies was identified. This could suggest an energy transfer. In the last interval, the thorax and upper arm energy decreases were positively correlated ($p<0.05$), and the hand and racquet and lower limbs increases were correlated negatively ($p<0.01$).

***Table 1.*** *Significant correlations between the normalized energy groups of player A*

| INTERVAL | Significant correlations between ± Δ of Ke | | | |
|---|---|---|---|---|
| t1-t2 | Tr/Ua<br>0.581* | Tr/ H&R<br>0.662* | Ua / La<br>0.776** | La / H&R<br>0.625* |
| t2-t3 | LL/Tr<br>0.661* | br/La<br>0.907** | LL / Ua<br>-0.664* | Tr/ La<br>-0.607* |
| t3-t4 | LL / H&R<br>0.570* | Tr/ La<br>-0.578* | | |
| t4-t5 | LL / Ua<br>0.601* | LL / La<br>-0.757** | Tr/ Ua<br>0.590* | |

** Significant correlations at p<0.05 and ** at p<0.01. Where LL = lower limbs; Tr = Trunk; Ua= upper arm; La= lower arm; H&R= hand and racquet.*

***Table 2.*** *Significant correlations between the normalized energy groups of player B.*

| INTERVAL | Significant correlations between ± Δ of Ke | | | | | |
|---|---|---|---|---|---|---|
| t1-t2 | Th-ua /H&R 0.698** | | | | | |
| t2-t3 | LL-pel/ Th-ua -0.711** | Th-ua / La 0.616* | LL-pel /La -0.676** | | | |
| t3-t4 | LL-pel / Th-ua 0.689** | Th-ua / La -0.733** | La / H&R 0.707** | LL-pel / La -0.774** | Th-ua / H&R -0.792** | LL-pel / H&R -0.599* |
| t4-t5 | Th-ua / La 0.579* | LL-pel / H&R -0.563* | | | | |

** Significant correlations at p<0.05 and ** at p<0.01. Where LL-pel= lower limbs and pelvis; Th-ua= thorax and upper arm; La= lower arm; H&R= hand and racquet.*

Theses previous results express the existence of an energy transmission pattern from the outermost body segment to the closer segment of the free end segment of the kinetic chain (the racquet). This pattern is followed by both players, and it explains the relationship between one segment energy decrease and the next participating body segment increase.

### *Hitting Pattern*

A discriminant analysis of the dependent parameters (body segment groups of normalized energies) was carried out to obtain a mathematical expression which would explain the individual hitting pattern of each player. Once the two performance levels were established, (“good” and “bad”), a discriminant function which establishes a linear combination between the dependent parameters while also allowing speculations about to be made on individual pattern of movements.

The discriminant function is positive, above 0, when the serves are from the Group 1 (“good”), and is negative, below 0, when the serves are from Group 2 (“bad”). It expresses the values which the parameters should reach taking care of the coefficient value and the sign of the parameters.

Player A discriminant function:

$$F(d) = -\,0.492\cdot(2.3\ \text{Tr Ke}) + 0.006\cdot(2.3\ \text{UA Ke}) + 0.269\cdot(3.4\ \text{Tr Ke}) - 0.25\cdot(2.4\ \text{La Ke}) + 0.483\cdot(4.5\ \text{Tr Ke}) - 0.474\cdot(4.5\ \text{Ua Ke}) - 0.071$$

0.934 Canonic Correlation
$p<0.05$
100% of the cases Predicted

Player B discriminant function:

$$F(d) = 0.003\cdot(2.4\ \text{La Ke})–0,103(2.3\ \text{Th-ua Ke})+0.176\cdot(4.5\text{La Ke})+0.66\cdot(3.4\text{LL-pel Ke}) + 4.855.$$

0,789 Canonic Correlation
$p<0.05$
78.6 % of the cases Predicted

**DISCUSSION**

The ball velocity achieved the level of the sample agrees with Elliott et al. (2003) which measured 41.5 m/s as the mean speed of the ball by radar of the 3 best serve from the female tennis players at the 2000 Sydney Olympic Games.

There are several studies on over hand throwing and hitting which have identified a movement pattern based on a sequence of body segment movements beginning with those far from the hitting segment and followed by the ones closer to it. In baseball pitching (Escamilla et al., 2001), in American Football (Fleisig et al., 1996) and in general throwing skills (Dapena & McDonald, 1989; Mero et al., 1994; Grande, 2000 and Morris, Barlett, & Navarro, 2001).

The Kinetic Link Principle (Kreighbaum & Barthels, 1981) found was based on a sequence of maximum kinetic energies from proximal to distal segments. There was no energy transmission at player A in the interval t1-t2. In t2-t3 the energy decrease at the lower limbs and trunk are related to the increase of the upper arm and lower arm energies. During t3-t4, the decrease of energy at the trunk was correlated with the energy increase at the upper arm and lower arm, once again. At t4-t5, there is a possible relationship between the energy loss of the lower limbs and the increase of the lower arm. Similarly there was no energy transmission at Player B in t1-t2 interval. During t2-t3 the energy losses of the lower limbs were connected to the increase of energy of the lower arm and thorax. At t3-t4 there were strong relationships between the decrease of energy of the lower limbs and thorax and upper arm, and the increase of the distal segments as the lower arm and hand and racquet. Finally during t4-t5, the deceleration of the lower limbs appeared to be related to the increase of energy of the hand and racquet.

The angular velocities recorded are shown in table 3 (Player B has negative values because she rotates in the opposite direction than player A through the Z axis). The pelvis and thorax rotation about the vertical axis measured by Fleisig et al. (2003) reached 440º/s and 870º/s, respectively. In this study, player A achieved 197º/s (Pelvis) and 405º/s (Thorax), and player B 416º/s and 618º/s. Upper arm internal rotation was studied by Elliott, Marshall, & Noffal (1995), and registered 2090º/s for amateur players and by Fleisig et al. (2003), who registered 2040º/s male and 1370º/s female tournament players. In this study player A upper arm internal rotation was 1962º/s and player B 1404º/s. While the players of this study obtained discrete values at the pelvis and thorax rotation, the upper arm internal rotation were both similar to results from Fleisig et al. (2003). Table 4 shows the key events sequence. Both coincided with Fleisig et al. (2003). The upper arm maximal internal rotation occurred as the last event, and the thorax rotation was previous to the pelvis rotation.

***Table 3.*** *Maximum angular velocities in º/s (B player data were – because she was left handed) (Mean±SD).*

| Player | Upper arm Internal Rot | Pelvis Rotation | Thorax Rotation |
|---|---|---|---|
| A | 1962±486 | 197±23 | 405±46 |
| B | -1404±506 | -416±51 | -618±55 |

***Table 4.*** *Key events from maximum angular velocities in s. where 0 is impact time (Mean±SD).*

| | A player | B player |
|---|---|---|
| Thorax Rotation | -0.135±0.014 | -0.090±0.027 |
| Pelvis Rotation | -0.088±0.037 | -0.027±0.034 |
| Upper arm Internal Rot | -0.006±0.018 | 0.021±0.011 |

We find relevant the fact that the sequence of angular velocities at the thorax, pelvis and upper arm found in this study and the previous studies do not show the sequence of maximum kinetic energies found from pelvis, thorax, upper arm, lower arm and finally at the hand and racquet segment. This could confirm the existence of a kinematic pattern different to the dynamic pattern. It is important to point out that in the kinetic energy; the rotation and translation movement are taken into consideration.

The individual technique pattern obtained by player A based on the discriminant function found, was more stable than that of player B. The equation reveals that during t2-t3 the player based her technique on a strong decrease of the trunk energy and high increase of the upper arm energy. The t4-t5 decrease of energy at the lower arm is higher in those serve which were classified as "good". Analysing the discriminant function from player B, The following events should occur: a moderate increase of energy of the thorax and upper arm at t2-t3, a moderate decrease of energy at the lower limbs at t3-t4 and at t4-t5 in the lower arm's energy. Finally, in opposition the increase of energy of the lower arm from t2 to t5 should be as higher as possible. As Reid, Elliott, & Alderson (2008) established, both players` technique depend on parameters related with the lower limb kinematics.

## CONCLUSION

There are no previous studies which have analysed the kinetic energy of the tennis serve which may be use for comparison. A model of energy transfer has been established for both players with the existing correlation throughout the intervals of the shot. With the discriminant functions recognised, the individual technique pattern of the shot has also been identified.

The lower limbs movements, principally the ankles and knees, were fundamental at the time to execute the best serves. This fact was previewed at the first qualitative analysis and it was confirmed with the discriminant analysis. Therefore, any biomechanical study of a tennis shot, should consider all body segment movements.

Many coaches tend to apply –reproduce- a universal pattern to their player. However, some authors support the idea that individual technical pattern should be carefully considered by coaches during the training process. A method has been developed which allows individual technique to be identify. This method has several advantages. The most important one is that the individual technique can be obtained without interfering the players' movement (external validity). Today it is possible to integrate a court in the biomechanics lab recording the movement at real time with 3D Capture System (i.e. Ariel, Vicon, SIMI); to create a virtual match situation where the player can perform the movements while the biomechanical parameters are being determined with a high external validity. In a short term period (no more than a week) the complete report of the biomechanical training session could be given to the coach (Elliott, Alderson, & Denver, 2007).

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