THE KINETIC CHAIN PERFORMED BY HIGH PERFORMANCE TENNIS PLAYERS

Cristina López de Subijana and Enrique Navarro*

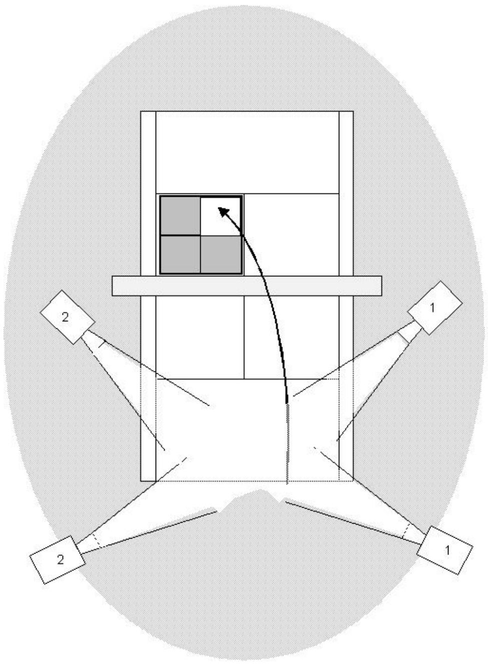
Physical Activity Institute, University of Alcalá de Henares, Alcalá de Henares, Spain
*** National Institute of Physical Education, Polytechnic University of Madrid, Madrid, Spain**

The tennis serve is one of the fundamental strokes in the development of the high performance tennis player. The aim of this study is to find the kinetic chain of two women professional tennis players' serve by means of 3D photogrammetric. The sample was 12 and 14 flat tennis serves, recorded with high speed cameras at 125 Hz. Their mean serve speeds were 38.1 m/s and 41.4 m/s. The mean of the angular velocities were 618 and 415 º/s at the thorax, 416 and 197 º/s at the pelvis; and 1404 and 1962 º/s at the internal rotation of upper arm. The kinetic energy was the biomechanical parameter considered. In both cases there was found significant energy transference between the body segments. Also, the kinetic chains found did not follow the key events of maximum angular velocities. Their parameters and "timing" were different between each player, in the way that they showed two models which were no compatible each other.

KEY WORDS: tennis, serve.

INTRODUCTION: The serve is a fundamental stroke in the development of the match and It could be the key of the outcome of a match. Speed of serve has been increased up to Andy Roddick's world record of 249.4 km/h during the 2004 season. (www.daviscup.com). A high speed serve, combined with a good percentage, guarantees more winning points and increases the probability of finishing the match successfully (Brody, 2003). Haake *et al.* (2000) proved that the faster the serve is, bigger than 160 km/h, the more errors at the opponent's return happened.
Recent studies approached the analysis of tennis with the angular velocities of different body segments, (Springins *et al*., 1994; Elliott *et al.,* 1995; Ito *et al*., 1995; Wang *et al*., 2000; Elliott *et al*., 2003; Fleisig *et al*. 2003). Elliott *et al.* (2003) and Fleisig *et al*. (2003) showed the angular velocities of the serves performed by the best tennis players at 2000 Sydney Olympic Games. The kinetic chain showed was in the following order: Knee extension, upper arm external rotation, trunk flexion, thorax rotation, pelvis rotation, elbow extension, wrist extension and finally the upper arm internal rotation. There were no previous studies considering the kinetic energy as a biomechanical parameter.
The aim of this study is to find the kinetic chain of two women professional tennis players' serve by means of 3D photogrametry. This kinetic chain will show whether the kinetic energy of the different body segments increases or decreases in relation to the others throughout the shot.

METHOD: The technique chosen was the 3D photogrammetry. The sample consists of 14 and 12 flat tennis serves performed by two high level women tennis players (between 40-60 WTA ranked). They were filmed with KODAK MOTIONCORDER Analyser SR-500-c high speed cameras at 125 Hz. Cameras were synchronized and placed in two different location because one of the players was left-handed. The calibration object was a cube of 2 m side. The serves to be tested were aimed at a target zone. (Figure 1)
The frames from all the sequences were manually digitalized and the DLT, Direct Linear Transformation and an algorithm was applied to get the 3D data.



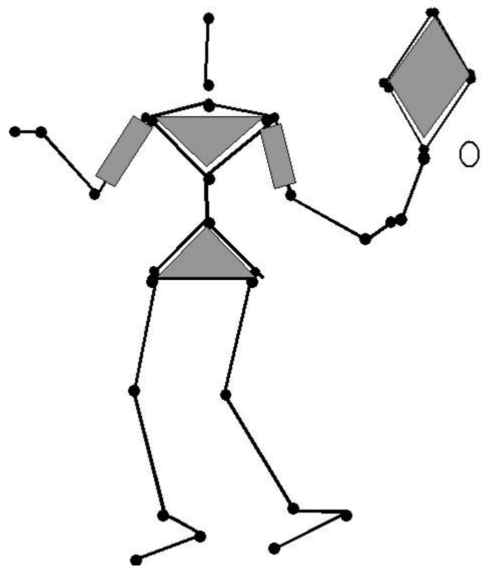
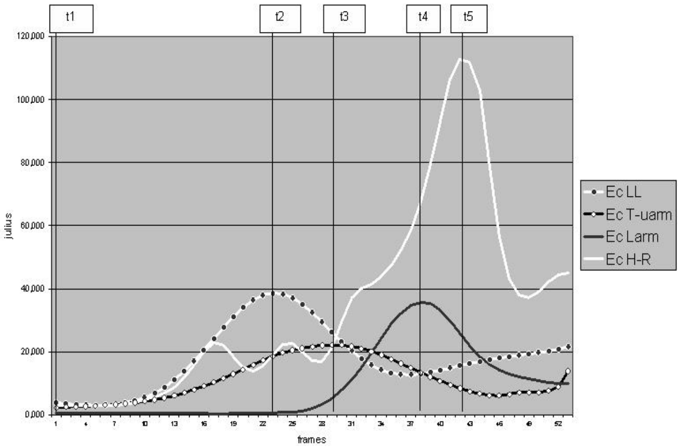


Figure 1 and 2: Camera location with target zone and 28 points mechanical model

The mechanic model is based on Clauser (1969) and Zatsiorsky *et al.* (1990). It is a 28 points model (23 from the body, 4 from the racquet and 1 from the ball). All segments were defined as bars except for 5 solid-rigids (pelvis, thorax, upper arms and racquet). The inertia parameters were taken from De Leva (1996). The tennis racquets were a “Fischer Pro One” and a “Volk Classic 7 Pro”, with length, mass and moment of inertia known. (Figure 2).
The data were filtered using the 5th order splines function (Woltring, 1985). The “mean true error “ from the manual digitalisation at the 3D of a point was 0,016 m. It is the result of digitalizing 3 individual frames 30 times.

RESULTS AND DISCUSSION: Speed of serve registered after the ball impact was 38.1 m/s, (150.9 km/h), in GL player and 41.9 m/s (137.2 km/h) in VR player. This data agrees with Fleisig *et al*. (2003) and Elliott *et al*. (2003), who registered a mean of 149.3 km/h for the women tennis serve.
The kinetic energy is considering as the sum of the translation and rotation of the body segment.
In order to compare the serves the kinetic energy was normalized in each interval. Both players had different techniques, one used the “foot up” while the other used “foot-back”, one used the “abbreviated swing” while the other used “full swing” technique. Analysing the kinetic energies of the body segments each player had different groups. Player GL had the kinetic energy in four groups: Ec Lower limbs, Ec Thorax-upper arm, Ec lower arm, Ec hand and racquet. Player VR had five kinetic energy groups: Ec Lower limbs, Ec Trunk, Ec, arm, Ec lower arm and Ec hand and racquet.
Figures 3 and 4 show the kinetic chain of GL and VR players’ serve. The t1 is the maximal knee flexion with both feet on the ground, and t5 is the maximum kinetic energy found at the hand and racquet segment.



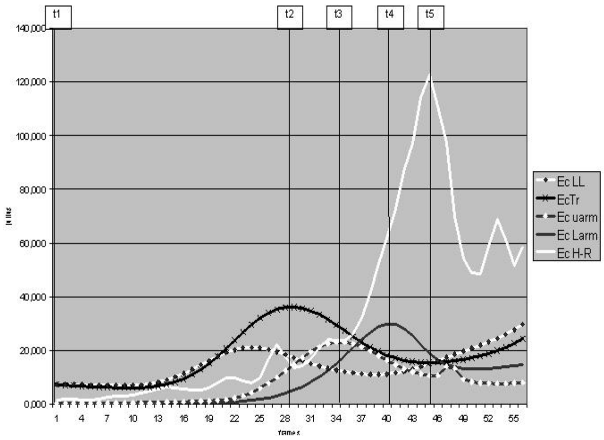


Figure 3 and 4: Kinetic chain from GL and VR player.

The significant correlations between each kinetic energy group are shown at the table 1.

Table 1: Significant correlations between the kinetic energy groups at GL and VR player

INT.	**Significant correlations between Δ of the kinetic energy groups GL player**					
t1-t2	T uarm/H-R					
	0,698**					
t2-t3	LL/T uarm	T uarm/Larm	LL/Larm			
	-0,711**	0,616*	-0,676**			
t3-t4	LL/T uarm	T uarm/Larm	Larm/H-R	LL/Larm	T uarm/H-R	LL/H-R
	0,689**	-0,733**	0,707**	-0,774**	-0,792**	-0,599*
t4-t5	T uarm/Larm	LL/H-R				
	0,579*	-0,563*				
INT.	**Significant correlations between Δ of the kinetic energy groups VR player**					
T1-t2	Tr/uarm	Tr/H-R	uarm/Larm	Larm/H-R		
	0,581*	0,662*	0,776**	0,625*		
T2-t3	LL/Tr	uarm/Larm	LL/uarm	Tr/Larm		
	0,661*	0,907**	-0,664*	-0,607*		
T3-t4	LL/H-R	Tr/Larm				
	0,570*	-0,578*				
T4-t5	LL/uarm	LL/Larm	Tr/uarm			
	0,601*	-0,757**	0,590*			

** Significant correlation at $p<0,01$
* Significant correlation at $p<0,05$

The significant correlation in each interval proved that there was a relationship between the decrease of a segment's kinetic energy and the increase of thenext segment in the proximal to distal kinetic chain.
The angular velocities found are in table 2. Data are similar to Fleisig *et al*., (2003) and they also occurred in the same order: first the thorax rotation, later the pelvis rotation and finally the internal rotation of the upper arm.

Table 2: Angular velocities and key events of GL and VR player in º/s. (GL is – because she was left-handed)

Player	**Maximum angular Velocity**		
	Upper arm	Pelvis	Thorax
GL	-1404 ± 506	-416 ± 51	-618 ± 55
VR	1962 ± 486	197± 23	405 ± 46

CONCLUSION: This study identified the kinetic chain of both players showing a sequence of maximums of the energy. This can be seen as the existence of a proximal to distal segments transference of energy.

The angular velocities may indicate that the kinematic pattern differs from the dynamic pattern. The kinetic energy included translation and rotation, while the angular velocity is measured through one axis. To our knowledge a kinetic pattern of the serve in tennis had not been found until now.

Each one of the players had a different pattern technique, in the way that is not possible to apply the same kinetic energy groups to both cases. This fact is very important for all tennis coaches working with high performance tennis players. They should be very careful and not force the athletes to reproduce a "universal pattern", but try to preserve the individual pattern technique, in order to obtain the best performance of their tennis player.

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