BIOMECHANICAL ANALYSIS OF THE UPPER EXTREMITY IN TENNIS SERVICE

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The purpose of this study was to calculate the external force, moment and power on the upper extremity of an elite player during the first service. The upper extremity of the subject was separated into three segments. The body segment parameter of the subject was calculated by using the mathematical model of truncated elliptical cone. The dynamical variables in the upper segment joints were determined via the 2D inverse dynamical solution. The present analysis shows the effectiveness of the truncated cone mathematical model as a high precision method for the calculation of body segment parameters. The wrist joint had been determined to sustain the greatest joint power during the contact phase. Regular training on the wrist extensors and elbow flexors is recommended for reducing the possibility of injury due to stress exerted on the flexor through eccentric contraction during the acceleration phase.

KEY WORDS: biomechanics, tennis, serve, inverse dynamics

INTRODUCTION: Tennis serve is one of the most important and powerful weapons among all tennis skills and techniques. The power service plays a very important role during a match. Previous studies related to tennis service had conducted by several researchers: Elliott et al (1986) analyzed the kinematics data of eight players. The initial velocity of the service of male players was averaged at 42.4m/s, with the linear velocity of the hip, shoulder, elbow, wrist, and racket at 2.0m/s, 2.7ms, 6.7m/s, 10.3m/s and 34.8m/s, respectively. Elliott (1988) claimed the service is the most important technique of the tennis game. The players should take care of the injury on the elbow and back, especially for the beginner. The purpose of this study is to analyze the net joint forces, moments and powers on the upper extremity of the elite tennis player during the flat service movement. In this study, we were interested in analyzing from the phase of the period before (-0.084sec) and after (0.034sec) the point at contact with the ball.

METHODS: An elite collegiate player in Taiwan was selected as the subject (192cm, 89kg). The upper extremity of the subject was separated into three segments, upper arm, forearm and racket (with fist included). The body segment parameter of the subject was calculated by a mathematical model of truncated elliptical cone (Fig.1) and calibrated by reaction board and water displacement method. Inertia data of the racket were directly determined by a pendulum technique. A Kodak Ekta-Pro 1000 high-speed video camera (500Hz) was used to record the 2D kinematics data. Figure 2 shows the schematic drawing of the experimental setup. The motions of the subject and the reference pole were recorded in the motion area. A successful trial was that the subject would serve the ball cross the net through the opposite court, and landed in the designated landing area as shown in Fig. (2). Eight 2D coordinates for the segment endpoints and racket were digitized and computed by Peak Performance Motion Analysis System. The dynamical models of upper limb segments are as shown in fig 3. The variables calculated included the body segment parameter of the upper extremity, the mathematical model of inverse dynamics, the kinematics and the kinetics variables. The inverse dynamical solution was employed to calculate the forces, moments and powers of the upper segment joints. From these data, we are striving to realize the dynamical characteristics of the upper extremity in tennis serving.

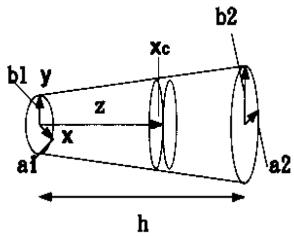

Figure 1 - Truncated elliptical cone.

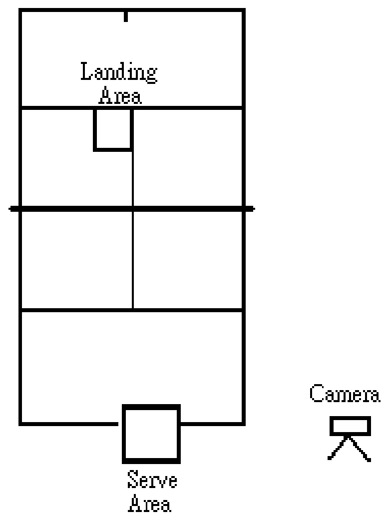

Figure 2 - Experimental setup.

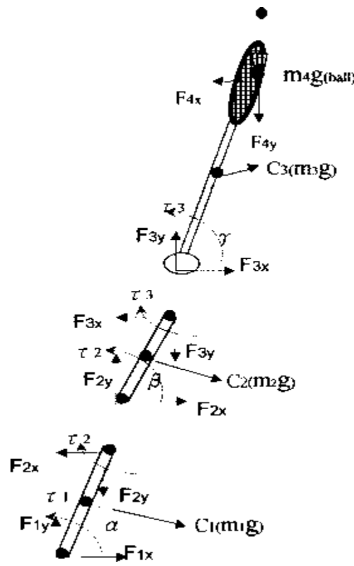

Figure 3 - Model of upper limb.

RESULTS AND DISCUSSION: The free diagram figure of the tennis serve is shown in Figure 4. The body segment parameters including the volume, the weight, the CM location in the segment, and the moment of inertia of the subject are listed in Table 1. The mathematical model of truncated elliptical cone employed in this study proved to be a very useful method. Table 2 shows the kinematics linear variables at contact. The time of the contact was 0.004 sec. The initial velocity of the ball was 61.5 m/s. The linear velocities of the upper limb segments at contact showed the velocities of the distal segments were faster than the proximal segments. The kinematics angular variables at contact are listed in Table 3. The angular velocity at the contact shows that the racket segment was faster than the forearm and the upper arm segment (wrist > elbow > shoulder). The patterns of the upper limb segments in tennis service are shown in figure 5. The net moment patterns are very similar among three joints with the wrist to be the most powerful joint in tennis service. Table 4 shows the dynamical analysis from the pattern of Figure 5. According to the study of Winter (1990), we measure the type of muscle contraction during the movement by calculating the angular velocity, the joint moment and the power of the joint. The power is given as,

Power • F × V • Moment × Angular Velocity(•)

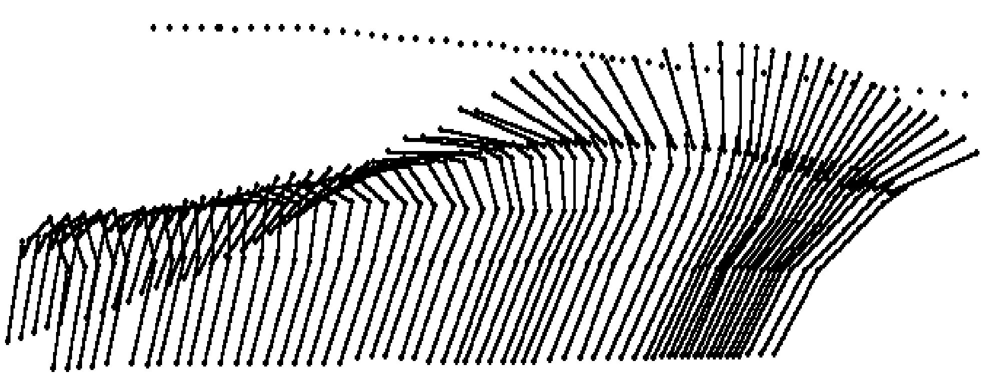

Figure 4 - The stick figure of the upper extremity in the tennis serve.

Table 1 The Body Segment Parameter

Variables of the Segments	Upper Arm	Fore Arm	Fist
Volume (cm³)	2508.6	1314.2	478.7
Weight (kg)	2.686	1.407	0.512
CM (%)	44.41	42.76	66.09
Moment of Inertia	0.03476	0.00512	0.00013

Table 2 The Kinematic Data at Contact

Kinematics Variables	Value
Contact Time (sec)	0.004
Initial velocity (m/s)	61.5
Flight Angle of the Ball (deg)	-7.8
The velocity of Hip (m/s)	1.1
The velocity of Shoulder (m/s)	2.0
The velocity of Elbow (m/s)	4.5
The velocity of Wrist (m/s)	10.4
The velocity of Racket (m/s)	34.0

Table 3 Angular Variables at Contact

Angular Variables	Value
The angle of shoulder (deg)	173
The angle of elbow (deg)	155
The angle of wrist (deg)	182
Shoulder angular velocity. (deg/s)	-248
Elbow angular velocity (deg/s)	-856
Wrist angular velocity of (deg/s)	-2622
Shoulder angular acc. (deg/s/s)	-9397
Elbow angular acc. (deg/s/s)	6270
Wrist angular acc. (deg/s/s)	343637

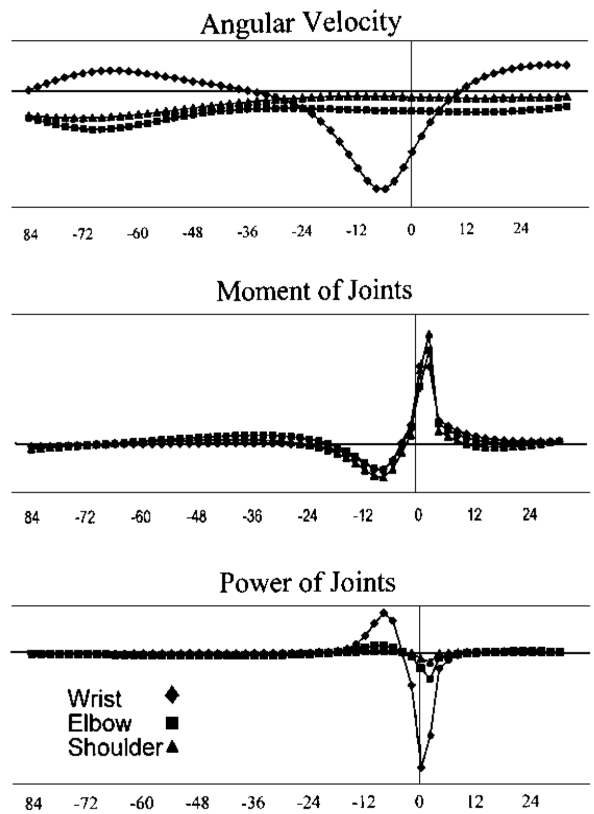

Figure 5 - The kinetic graph of service.

Table 4 The Dynamical Analysis

Variables	Upper Arm	Forearm	Racket(fist)
Angular Velocity	□	□	□
Moment of Joints	□□ +	□□ +	□□ +
Power of Joints	+□□	+□□	+□□
Muscle Contraction	Concentric □ Eccentric	Concentric □ Eccentric	Concentric □ Eccentric
Functions	Flexion □ Constrain	Extension □ Constrain	Flexion □ Constrain

From the previous equation and the graph of Figure 5, we summarized the characteristics of the upper limb segments around contact in Table 4. Before contact of the power service, all the three segments exerted concentric contraction first (-20 msec before contact), and the eccentric contraction followed. The eccentric contraction was generated through the contact point from -6 msec before contact to 8 msec after contact. The muscles of the shoulder joint flex forward to fix the shoulder joint. The elbow joint extended first, to stabilize the muscles of the elbow joint. The muscles of the wrist joint flexed first, to constrain the wrist join. The function of eccentric power may serve to absorb the concentric power and to protect the joints from injury during tennis serving.

CONCLUSIONS: This study described the different biomechanical characteristics of the upper extremity of an elite tennis player in Taiwan. The results showed that the mathematical model of truncated elliptical cone employed in this study provides a very useful and accurate method for the calculation of body segment parameters. The kinematics data of this study agreed well with that of Elliot et al (1986). The analysis shows that the wrist joint has the greatest angular velocity, angular acceleration and joint power during the contact phase. The extensors of the shoulder and the wrist joints, the flexor of the elbow joint were found to suffer the eccentric contraction before contact. This is the reason why the new learners are always experiencing pain of the wrist extensors, elbow flexors or shoulder extensors. It is recommended that a regular training on the wrist extensors, elbow flexors and shoulder extensors will reduce likelihood of injury through eccentric contraction during contact phase.

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