KINETICS OF THE COMPUTERSIMULATED TENNIS STROKE WITH DIFFERENT RACKETS

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INTRODUCTION:

The aim of this biomechanical analysis of the tennis stroke is the determination of the effects of the mass properties of different tennis rackets on the kinetics of the striking arm.

The quite complex movement of the tennis stroke depends on many factors as there are for example the players anthropometry (CASOLO, 1993), the grip force (KNUDSON, 1989) and especially the biodynamical properties (HATZE, 1994) of the tennis racket. When the sweet point of a racket is hit the induced grip force during the impact phase is minimized. The centre of percussion (COP) and the nodal point of the first transversal vibration are connected with this special point. The distance between the COP and the nodal point of the racket determined by HATZE (1994) is only several millimetres.

In contrast to experimental investigation the computer simulation gives an infinite temporal resolution so that the analysis of the arm movements could be investigated especially during the impact phase. Another advantage of the computer simulation is the possibility to vary the interesting parameters separately and continuously. As we have only considered rigid body mechanics so far our focus of interest is on the following questions:

1) Do the kinematics of the striking arm depend on the different mass properties of different tennis rackets?

2) Which is the influence of the COP on the arm´s kinematics?

3) Is a reasonable classification of tennis rackets with respect to rigid body mechanics possible?

4) Might our computer simulation be helpful for an individual choice of a tennis racket?

METHODOLOGY:

The planar model of the tennis stroke consisting of the immovable trunk, the upper arm, the lower arm, the hand and the racket was derived from the mathematical model of the human body developed by GLITSCH (1993). The striking arm with a variable hand-racket-connection was constructed as a pendulum of three rigid bodies which are connected with frictionless revolute joints. An elastic spring with its spring constant of 45000 N/m represents the racket-ball-contact. The stretched arm-racket-system rotates around the shoulder joint with an angular velocity of 17,45 rad/s and the resting ball is hit in a definite contact point on the racket area. These initial conditions of the simulated tennis stroke are adjusted in order to get kinematics of a real tennis stroke registered by ELLIOTT (1989) and a duration of contact referring to CASOLO´s (1991) investigation. The mass properties as there are the mass, the moment of inertia and the location of the mass centre as well as the racket area centre were measured. The mass properties of five modern carbon fibre tennis rackets served as input for the model. The calculation of this simulated tennis stroke was carried out with the software-packet DADS (Dynamic Analysis and Design System) by CADSI (Computer Aided Design Software Inc.).

We determined the COP of the striking arm assuming a slack hand-racket-connection by considering the induced grip force and varying the hitting points at the longitudinal axis of the racket until the normal component of the grip force is less than 1 N as it is described by DETLEFS (1995). Then the arm-racket-system is changed by defining a tight racket-hand-connection and a new COP according to the elbow is determined in the same manner.

Besides the impact kinetics of forehand strokes with the five tennis rackets were calculated with respect to their individual centre of area as contact point by striking with a tight grip.

RESULTS:

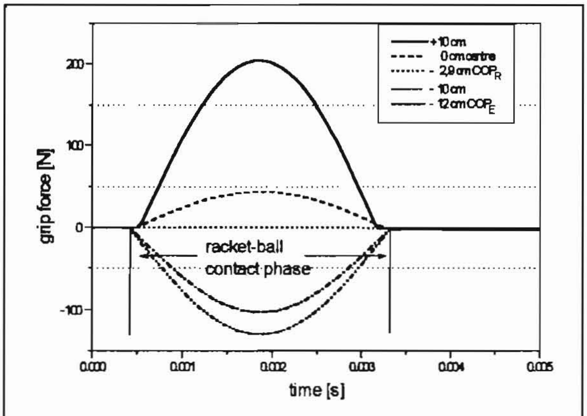

Fig.1: *Normal component of the induced grip force in dependence of the hitting point along the longitudinal axis of racket 3 with a slack grip*

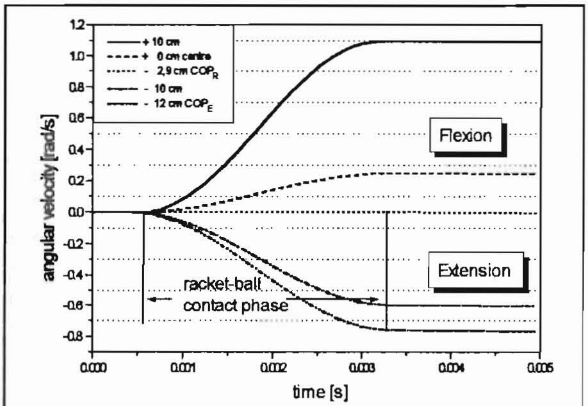

Fig.2: *Angular velocity of the elbow in dependence of the hitting points along the longitudinal axis of racket 3 with a slack grip*

Under the assumption of a slack hand-racket-connection the normal component of the induced grip force disappears (becomes less than 1 N) when racket 1 is used at a hitting point 2,9 cm proximally from the centre of area as can be seen in figure 1. The still stretched arm-racket-system rotates without any joint movements after the racket-ball-contact because no force is induced to the grip by the impact. This hitting point is therefore the COP according to all joints of the striking arm as CASOLO (1991) theoretically predicted. We defined this point **COP of the racket (COP$_R$).**

We examined the kinematics of the striking arm by focusing on the elbow movement. The resulting angular velocities of the elbow when the tennis strokes with racket 3 at different hitting points are considered are given in figure 2. The time histories show that during the impact phase either a positive or a negative angular velocity of the elbow is induced resulting accordingly in a flexion or an extension of the elbow. The explanation for the different elbow movement is the relation between the hitting points of the racket and the COP$_R$. If the contact points are located more distally than the COP$_R$ the elbow is getting flexed during the impact phase. The contact at the more proximally contact points forces the elbow to its extension. The greater the distance between hitting point and COP_R is the bigger is the angular velocity. We draw the conclusion that generally the COP is even a point of change with respect to the dynamics.

Assuming a tight hand-racket-connection during the tennis stroke with racket 3 no elbow load is calculated when the ball hits the racket 12 cm proximally from the area centre. With reference to the definition of COP_R we called this special point **centre of percussion of the elbow (COP_E)** (see table 1). The elbow kinematics of the strokes with a tight grip are shown in figure 3. As all hitting points of racket 3 investigated in this study are located distally from this COP_E the impact dynamics causes the stretched arm to the anatomically possible elbow flexion.

It can be seen from table 1 the COP_R of the five racket are located in a distance between 2,2 cm and 5,5 cm proximally from the respective area centre. The hitting point where is no force transmitted to the striking arm with a tight grip is shift towards to the grip near the end of the racket area (10,2 cm till 13,8 cm proximally from the centre). The tennis strokes with different rackets in the centre of each racket cause different angular velocities (2,05 rad/s till 2,75 rad/s) of the elbow presented in figure 4.

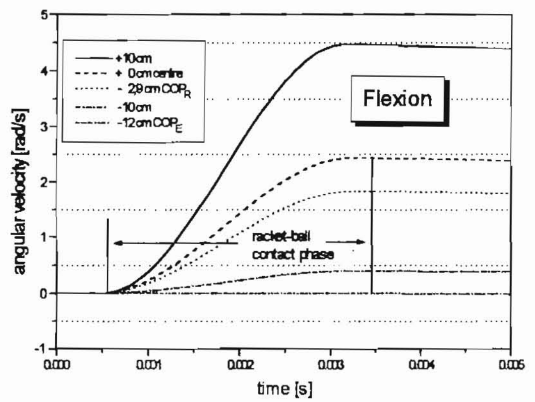

Fig.3: *Angular velocity of the elbow joint in dependence of the hitting points along the longitudinal axis of racket 3 with a tight grip*

The greatest in this study calculated elbow angular velocity of 4,5 rad/s can be counteracted by muscular activity. A danger of injury however should exist during the tennis stroke with a stretched arm and a slack grip because the contact dynamics induce an impact on the bone blocked elbow joint.

Tab.1: *Mass properties and different centres of percussion of the tennis rackets; distance according to the respective centre of the rackets' hitting area; moment of inertia referring to an axis through the mass centre*

	mass [kg]	distance of mass centre from grip end [m]	moment of inertia [kgm²]	COP_R [cm]	COP_E [cm]
racket 1	0,375	0,337	0,0154	-0,055	-0,131
racket 2	0,363	0,323	0,0172	-0,051	-0,138
racket 3	0,338	0,317	0,0157	-0,029	-0,12
racket 4	0,368	0,321	0,0167	-0,022	-0,106
racket 5	0,322	0,369	0,0122	-0,025	-0,102

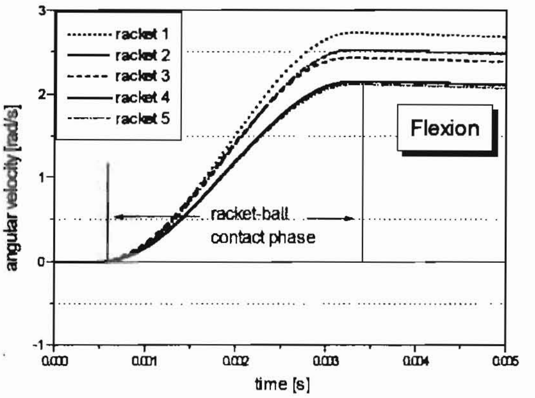

***Fig.4:** Angular velocity of the elbow during the tennis strokes with different rackets at their respective centre of area (tight grip)*

CONCLUSION:

With respect to rigid body mechanics the COP_R was discussed as one of the biodynamical properties of a tennis racket (HATZE 1994). If the striking arm is changed by a tight grip the COP_E is the hitting point so that no force is transmitted to the arm during the impact. There is a possibility for the player to adjust the location of the COP to the anticipated hitting point between the COP_R and the COP_E by varying the grip force. The different mass properties of the tennis rackets are responsible for the different locations of the COP_R and COP_E on the racket area. The location of the COP_R and the COP_E in relation to the hitting point is the decisive factor for the different elbow movements during the impact phase.

Our investigations by computer simulation of the tennis stroke have so far resulted in considering the COP_R and defining a parameter, the COP_E, which are derived from the individual mass properties of each racket and of the additional mass properties of the hand. Therefore the COP_R and the COP_E as well as their distance are a base for the classification of tennis rackets.

A more advanced model should be of assistance for the choice of an individual racket, which might minimize health risks. On that lead further investigation of the computer simulation should take into account the flexible properties of the tennis racket.

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