EFFECTS OF USING DIFFERENT MOMENT OF INERTIA OF RACKET ON TENNIS SERVE

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The purpose of this study was to investigate the kinematics and kinetics of tennis flat serve by using different moment of inertia (0.0285, 0.0309, 0.0336, 0.0415 kg*m^2) of racket. Inverse dynamics method was used to calculate net joint reaction forces, net muscle joint moments and powers of the wrist, elbow and shoulder during pre- and post- impact. The result indicated the trend that the less moment of inertia generated the greater speed of racket head, but the effect of moment of inertia on the racket's angular velocity was not obviously. There were similar kinetic patterns among all players while using their own racket, but different patterns while using the racket with maximal moment of inertia. Further, there were relationships existed between racket's angular velocity and the relative kinetic patterns.

KEY WORDS: tennis, moment of inertia, inverse dynamics

INTRDUCTION: The serve is the most important skill in tennis and the flat serve is the most powerful one among many different patterns of serve. Besides the player's skill, ball and court properties, the racket is also one of the important factors that affect the serving performance. Therefore, most professional tennis players are not only considering the mass and balance point of the racket but also pay attention to the moment of inertia (MOI) in their process of choosing the racket. The MOI about the axis through the handle at the butt end and in the plane of the racket head is known colloquially as the "swing weight" (Brody, 1985). It also means that how heavy the racket is felt when you swing it. Using racket with larger MOI imply that it's hard to swing and need greater effort to achieve the same racket speed. However, there is usually an increase in racket power in compensation of your effort (Brody, 2000). Change the racket's MOI influenced the player's feeling (Beak, Davids & Bennett, 2000). Mitchell, Jones, & Kotze (2000) indicated that racket head speed increases with reductions in mass and MOI. Further, when normalized with respect to the individual player's performance with their own racket, the results showed a consistent relationship between the racket head speed and the racket's MOI for all players. During the serve, force starts with ground reaction forces, then successively transfers through the upper limb shoulder, elbow, and wrist to the racket. The velocity of upper limb segments increased as the kinetic chain. The maximal velocity of the joints occurred before ball impact and the distal joint was closer to the maximal velocity while approaching ball impact (Van Gheluwe & Hebbelinck, 1983; Elliott et al., 1986; Elliott, 1988; Elliott et al., 1995). If the MOI of racket was changed or on the other hand that means the distal parameter of the upper limb was changed, then the player should adjust his body at the optimum position to hit the ball. Each body segment is successively linked together. Integration of body moment proceeding by the interaction of multisegment has the complexity to depict and explain its phenomenon through the external kinematical parameters. In order to understand how the racket MOI effects tennis serves, it's necessary not only to observe the change of kinematical parameters but also to investigate the cause of internal kinetically response. The study investigated kinematics and kinetics of the flat serve by using different racket MOI. The net joint reaction forces, net muscle joint moments and powers of the wrist, elbow and shoulder were calculated by applying the inverse dynamics method. The contribution of upper limb and kinetic patterns was sought during pre- and post- impact.

METHODS: Four elite female tennis players participated voluntarily in this study. Their mean age, height, weight and training years were 22.5±2.7years, 1.66±0.06m, 62.3±8.9kg and 13.3±4.1years, respectively. One Redlake1000 high-speed camera was operated at 500Hz and was used to record the participators when they performing the flat serve. The camera was set up to record the movement of the upper limbs in the sagittal plane. The upper limbs included three-segment upper arm, forearm and hand with racket. Four landmarks were placed on shoulder, elbow, wrist and the racket head. Each player was asked to finish three good service shots with their own racket and other rackets with different MOI. The highest ball speed data were analyzed. Dempster's data were used to calculate the segment parameters. The inverse dynamics process was used to calculate net joint reaction forces and net muscle joint moments, where $F=m \times a$ (F: net joint reaction forces, m: mass of the segment, a: acceleration of the CG of the segment) and $M=I \times \alpha$ (M: net muscle joint moments, I: moment of inertia of the segment about the axis through CG of the segment, α: angular acceleration of the segment with respect to horizontal axis). The net muscle joint powers were calculated as $P=M \times \omega$(ω: angular velocity of the joint). Due to different racket properties, this experiment requires four identical rackets. To control the MOI of racket, a mass of 0.04kg was added to different positions of each racket. Figure 1 shows the positions of extra weight at the racket head, side, throat and butt end. Figure 2 shows the MOI measuring by Babolat Racket Diagnostics Center. Table 1 lists the racket properties.

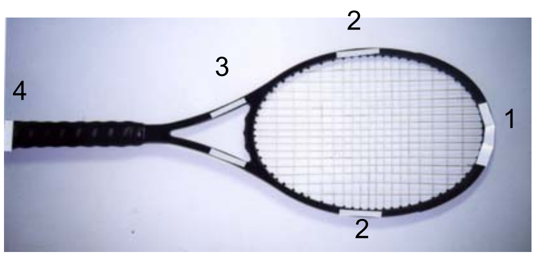

Figure 1-The position of extra weight.

Figure 2- Measure the moment of inertia of racket.

Table 1 Experiment Racket Properties

Racket	Mass (kg)	Length (m)	Balance point (m from butt end)	Moment of inertia (kg-m^2 70mm from butt end)
1	0.320	0.685	0.376	0.0415
2	0.320	0.685	0.350	0.0336
3	0.320	0.685	0.335	0.0309
4	0.320	0.685	0.298	0.0285
Player A's	0.319	0.685	0.333	0.0309
Player B's	0.308	0.685	0.327	0.0282
Player C's	0.356	0.685	0.309	0.0316
Player D's	0.293	0.695	0.355	0.0310

RESULTS AND DISCUSSION: Figs. 3, 4 show results of four players with different MOI racket at impact. Fig. 3 indicated the trend that the less MOI generated the greater speed of racket head, and supported the previous study by Mitchell et al. (2000). After compared each player's own racket with four experimental rackets, each player had higher head speed at impact while using the racket with minimal MOI. Figure 4 indicated that the effect of MOI on the racket's angular velocity with respect to the forearm was not as obvious as the velocity of racket head. Further, the maximal angular velocity of racket almost appeared at the instant of ball impact from three of four players while using the racket with least MOI (racket 4).

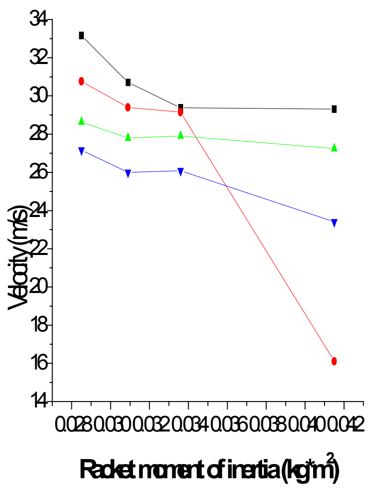

Figure 3-Racket head speed vs. moment of inertia at impact.

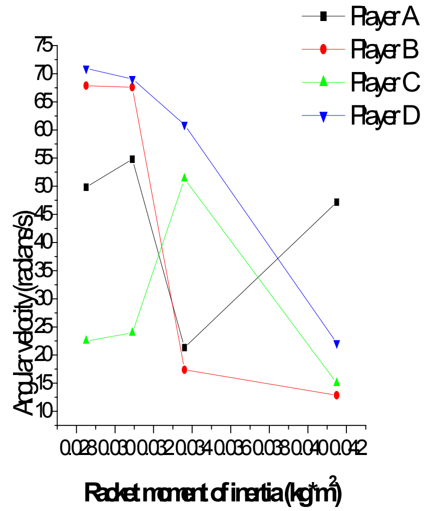

Figure 4-Racket angular velocity vs. MOI at impact.

According to the study of Winter (1990), the net muscle joint moments can be utilized to determine whether extensors or flexors dominating the movement of the joint. The polarity of net muscle joint powers indicated that the muscle group was under concentric or eccentric contraction. In this study, when angular velocity was positive, it means the wrist extended and the elbow flexed. When net muscle joint moments were positive, it means extensors of wrist and flexors of elbow dominating the muscle activity.

During impacting the ball by racket with the maximal MOI, the net joint reaction forces of wrist (334.5N±33.6) were obviously higher than that with the minimal MOI (276.5N±36.5). All players had the similar kinetic patterns with their own racket but the discrepancy with the maximal MOI of racket. Figure 5 shows in the process of forward acceleration, the elbow extensors were contracting concentrically to extend the elbow and wrist was relaxed. Just 30 ms prior to impact, the elbow flexors were contracting eccentrically to stable the elbow. At the same time, the wrist extensors were also contracting eccentrically that was used to resist the racket's inertia. At the impact phase, the elbow extensors and wrist flexors were contracting concentrically to hit the ball, and the net muscle joint powers of wrist reached the maximal value. Three of four players had similar kinetic patterns with the two less MOI, but the kinetic patterns differ from that of using their own racket. There were clearly fluctuations that the wrist muscle group showed a sequence of concentric extension, concentric flexion, and eccentric extension before ball impact. This reason maybe attributed to the racket with less MOI that was easier to swing so the players were able to control the activity of wrist. The contribution of wrist flexors concentrically contracted was giving more power on the racket.

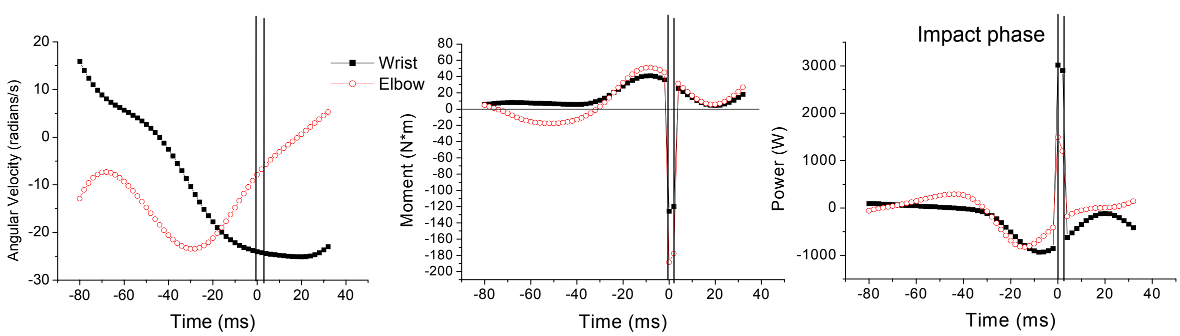

Figure 5-Relative angular velocity, net muscle joint moments and net muscle joint powers of wrist and elbow in the process of forward acceleration.

The result also indicated that the relationships between racket's angular velocity and the kinetic patterns. While using the racket with larger MOI, due to it's hard to swing, the performance of the segments should be more relaxed. However, "relax" of segments means sequential condition between each segment, and the momentum could be transferred from the proximal to distal of the upper limb. How to transfer the energy? The upper limb of human body has three segments, each segment link by the joint, if the forearm contracting eccentrically to reduce the angular velocity before ball impact, then the racket will gained more angular velocity finally.

CONCLUSION: This study investigates the effect of using different moment of inertia of racket on tennis serve. The result indicated the trend that the less moment of inertia generated the greater speed of racket head, but the effect of moment of inertia on the racket's angular velocity was not obviously. There were similar kinetic patterns among all players while using their own racket, but different patterns while using the racket with maximal moment of inertia. Further, there were relationships existed between racket's angular velocity and the relative kinetic patterns. For the beginners, choosing the less moment of inertia of racket will easier to handle and won't cause physical problems. For the experienced or professional tennis players, it depends on their own athletic ability, skill, strength and the different playing forms. In this presentation, we suggest that it's necessary to train the eccentric strength of wrist joint to avoid the wrist injury from tennis serving.

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