ENERGY EFFICIENCY OF DIFFERENT TENNIS RACKET STIFFNESS AND STRING TENSION DUE TO CENTER AND OFF-CENTER IMPACT

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The purpose of this study was to investigate the power of vibration responses and moments of different racket flexibilities and string tensions following center and off-center impacts. Three rackets, classed as stiff, medium, and flexible by their manufacturers, were strung at three string tensions and subjected to 15 trials. The rackets were gripped on a KISTLER force plate and impacted at designated areas by a rigid ball. The stiff racket had smaller powers of vibration and twisting moment for each string tension in off-center impact. The largest power of vibration and twisting moment occurred respectively in the flexible racket strung with 50pound and medium racket strung with 70 pound in off-center impact.

KEY WORDS: moment, power, vibration response, power spectrum

INTRODUCTION: When tennis rackets experience off-center impacts, the racket vibration modes included divining board, bending, and twisting (Lin, 1998). For beginners, high probabilities of off-center impacts may cause the twisting vibration, and decreased control and power of hitting. Because of racket twisting, injury of fatigue may be caused to the muscles that stabilize or move the wrist joint. The effects of racket twisting has also been reported to reduce the ability of damping in the hand-arm system (Eward & Henning, 1992). A racket produces torques along the long axis passing through the center of mass when a ball is hit off-center. The torques and vibrations transmit to the human arms basically sinusoidal functions. But the polar moments of inertia of rackets determine the resistance to twisting. The value of the moment is proportional to the racket mass times the maximum width of the head squared (Brody, 1985). Branign and Adali (1981) reported that the moment of inertia along the polar axis passing through the center of mass did not distribute uniformly. Thus, it can be inferred that the vibrations along the polar axis also do not distribute uniformly. For the interaction of racket stiffness and string tension, Bitz and Moeinzadeh (1990) used finite element techniques to model a tennis racket with variable string patterns and tensions. They found that the strings not only stiffen the racket and redistribute the load but they also decrease the angle between the racket head and the applied load. The best way to increase the control of off-center hitting was by increasing racket stiffness, string tension, and width of the racket head, although this could produce a higher vibration frequency (Branigan & Adali, 1981; Brody, 1989). Irrespective of center or off-center impacts, with a lower string tension (50p~55p) and suitable racket stiffness, the rebound velocity of the tennis ball could be maximized (Baker & Wilsin, 1978; Elliott, 1982). The purpose of this study was to investigate the energy efficiency (power) of vibration responses and moments of racket of different flexibility and string tension following center and off-center impacts.

METHODS: Three hyper carbon rackets were selected for use in the current study. In an attempt to standardize the influence of flexibility, the three rackets were classified as stiff, medium, and flexible following static load tests by a BABOLAT Racket Diagnostic Center machine. Prior to testing, each racket was strung with Prince synthetic gut 16L at different tension of 50p, 60p, and 70p. The three rackets were gripped on a KISTLER force plate. A rigid ball (0.169 kg) positioned at a height of 1 meter was dropped to the racket. The ball impacted vertically on the geometric center and off-center area of each of the three rackets (Figure 1) the two areas were impacted for 15 trials. The sampling rate and data capture time of the force plate was set at 2048Hz and 5 seconds, respectively.

Analysis Methods: The raw data were measured by Bioware software and vibration forces were analyzed by Fast Fourier Transform into the frequency domain.

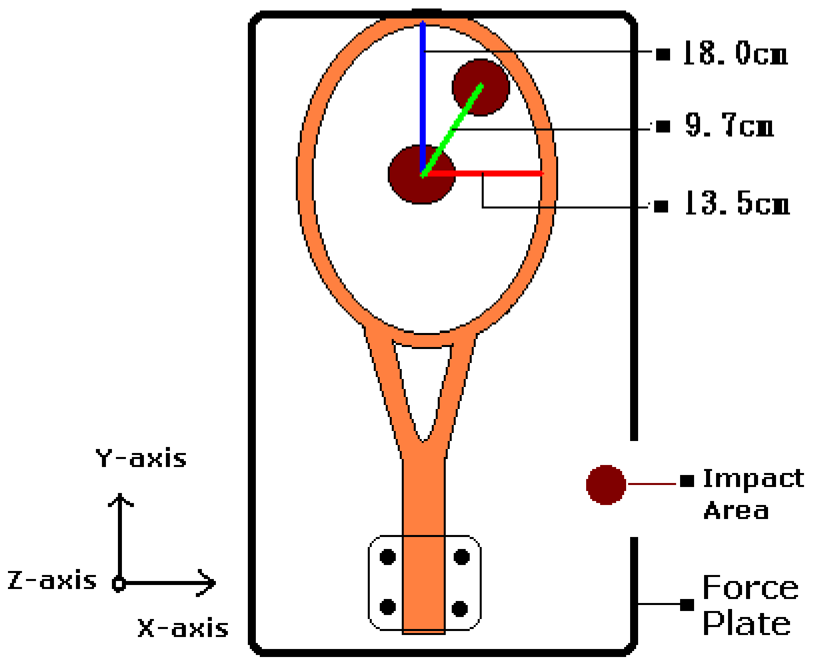

Figure 1 - Impact area and coordinate system.

RESULTS AND DISCUSSION: For off-center impacts, all of the rackets gave significantly higher power of vibration responses than in center impacts. The smallest value of vibration power was found for a center impact on the medium stiffness racket with a string tension of 50p. The result supported the finding of Baker & Wilson (1978) and Elliott (1982), who found a racket of medium flexibility strung with 50~55p had the best ball velocity ratio. According to the conservation theorems, the more elastic energy stored by the tennis balls, the less vibration energy rackets produce. The higher rebound velocity of the tennis ball indicated that more energy was transmitted into the tennis ball in the form of kinetic energy. In off-center impacts, the flexible racket, strung with 50p if tension, had the largest power of vibration responses. Decreasing string tensions tended to change the stiffness of the flexible racket, and increased dwell time (dwell time is defined as time of the ball staying at the racket) of the tennis ball may cause a loss of a large amount of energy into racket twisting and vibration.

The moment of the rackets was measured along the long axis passing through the handle grip. This study found that the mode of moment was the same as the force vibration mode (Brannigan & Adali, 1981). But it was very difficult to investigate the racket twisting by analyzing the frequency domain of the moment. This was especially true under dynamic conditions, the vibration moment was inconsistent for several modes including divining board, bending, and twisting.. No significant difference was found in the moment magnitude of the stiff racket for the changes in string tension for center impact. However, the smaller power of moment for every string tension occurred in the stiff racket for off-center impact (Figure 2).

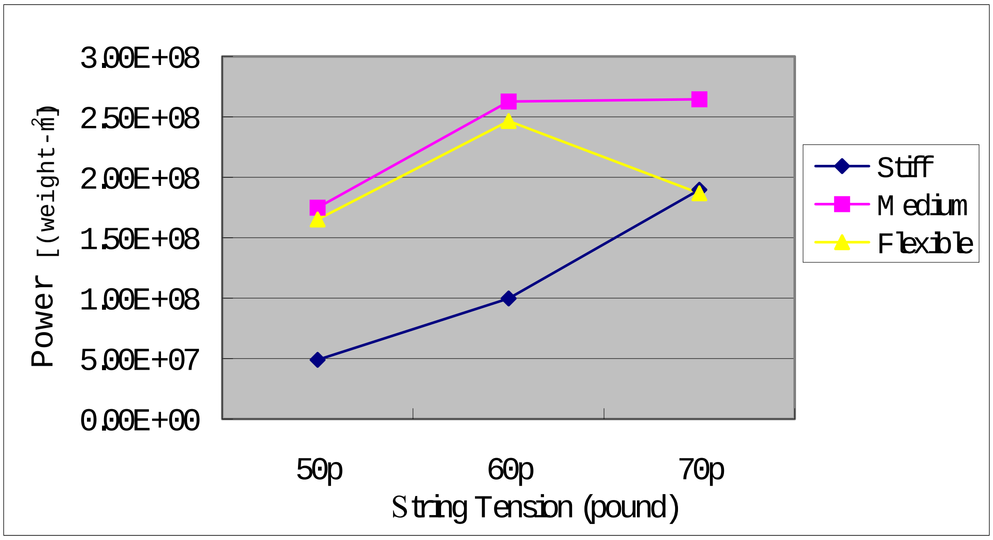

Figure 2 - The relative total power of moment in off-center impact.

The results showed that the structures of the stiff rackets are more stable and suitable for controlling the tennis ball for off-center impact. That was the reason that increasingly stiff rackets were introduced (Brody, 1995). This study also found that the racket of the medium flexibility had the higher total power of vibration response and moment compared with the other rackets with a string tension of 70p. The increased string tension affected the stiffness and settling time of vibration for the medium racket.

CONCLUSION: Racket stiffness and string tension both influence the level of vibration and twisting. All of the rackets increased the force vibration with increases in string tension under center impacts. However, it was found that the effect of off-center impact for the hand-arm systems was more significant than in center impact. Generally, the stiff racket had smaller power of the force shock and twisting moment for each string tension in off-center impact. This may impair the control of balls struck off-center (Brody, 1979; Brannign & Adali, 1981). The largest force power shock was occurred with the flexible racket strung with 50p and the largest twisting moment occurred with the medium racket strung with 70p in center and off-center impact.

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