STUDY OF VIBRATIONAL WAVES OF VARIOUS TENNIS RACKET MATERIALS AND THEIR RELATION TO PERFORMANCE CONTROL

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This study investigated vibrational waves of various tennis racket grip materials by studying maximum amplitude and settling times. Five different kinds of tennis racket grips were used, and the materials were composed by mixing carbon and glass fiber. A second purpose was to distinguish performance control by the five kinds of tennis racket. The results of this study indicated that the pure carbon fiber racket had a shorter settling time ($p<.05$). However, the maximum amplitude was not significantly different. This study significantly confirmed that this phenomenon would indirectly affect an athlete's ability in performance control.

KEY WORDS: racket, vibration, settling time, composite material

INTRODUCTION: Many people believe that modern rackets generate much more power than earlier rackets. Part of the increase in power could be attributed to stronger, better conditioned players, but the major reason was the modern racket of the consistent power making it possible. Many factors are important elements in selecting tennis equipment. However, it's obvious that the tennis industry is still thriving (Groppel, 1992). Equipment will continue to improve. Manufacturers have identified the needs to help the game by suggesting players about what kinds of equipment to look for and how certain pieces of equipment might benefit them. The trend of today's racket industry is toward the carbon/glass fiber composites and meteoric materials of viscoelastic polymers (Brody, 1995). Out of all the materials available, carbon fiber is used most often and it is usually combined with glass fiber. There were also many methods to analyze the vibration of tennis racket (e.g., frequency spectrum and settling time). The purpose of this study was to analyze the vibrational waves of various tennis racket grip materials for top, bottom, and center impacts of the racket face through maximum amplitude and settling time. In addition, performance control was distinguished among five different tennis rackets.

METHODS: Five different kinds of tennis racket grips were chosen for this study. The manufacturing materials used were composed by mixing carbon fibers and glass fibers in the ratio of 10 to 0, 7 to 3, 5 to 5, 3 to 7, and 0 to 10. They all had the same weight, string tension, stiffness and balance. One experiment of the study was to test amount vibration (first mode) and to find out the settling time and maximum amplitude of vibrational waves. And the other experiment was to distinguish the performance control among the five different kinds of tennis rackets.
Two accelerometers (2000 Hz) and BioPAC system were used to acquire the vibrational signals. The impact of the tennis ball was set at a velocity of 4.09 m/s. Twelve elite athletes (Table) served as the subjects to conduct the test of performance control of the forehand

Table 1 Physical Characteristics of Subjects (n•12)

	Age (years)	Height (cm)	Weight (kg)
Average	21.8	175.1	67.5
Standard deviation	2.3	6.4	5.1

volley (40 times). The tennis ball of serving machine was set in the velocity of 30 m/s, and the selected variables in the experiments were tested by one-way ANOVA at α=.05 significant level.

The value of performance control • (Score of testing racket) ÷ (Score of accustomed racket) for 40 times per racket

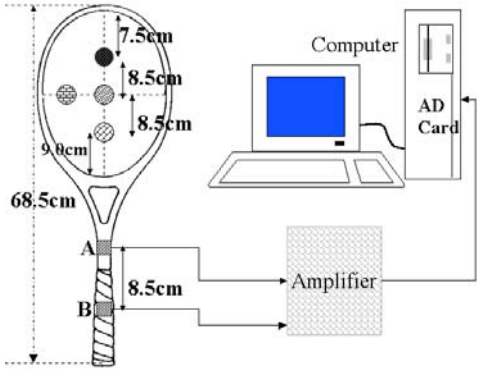

Figure 1 - Accelerometers (point A and B) measuring chain.

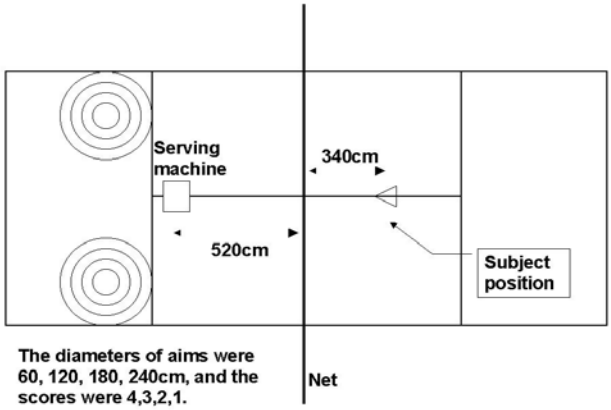

Figure 2 - Testing court of performance control.

RESULTS AND DISCUSSION: The results of this study indicated that the pure carbon fiber

Table 2 The Mean and Standard Deviation of Settling Time with Various Tennis Racket Grip Material (unit : msec)

Percentage of carbon Impact position	100%	70%	50%	30%	0%
Center impact*	92.30	103.80	99.50	106.80	107.00
n=5	(1.57)	(2.17)	(1.12)	(1.30)	(2.55)
Top impact*	92.50	94.50	103.50	113.00	111.00
n=5	(1.71)	(2.36)	(1.71)	(1.32)	(5.66)
Bottom impact*	108.50	110.50	113.50	117.00	121.00
n=5	(1.72)	(2.12)	(2.12)	(1.82)	(2.28)

( ): standard deviation for five times per racket
*: mean statistically significant differences, $p<.05$

racket had a shorter settling time (msec) on the center (92.30) and off-center (92.50; 108.50) impact (Table 2). The settling time was significantly increased, as the content of glass fiber in the racket was increased (Figure 3).

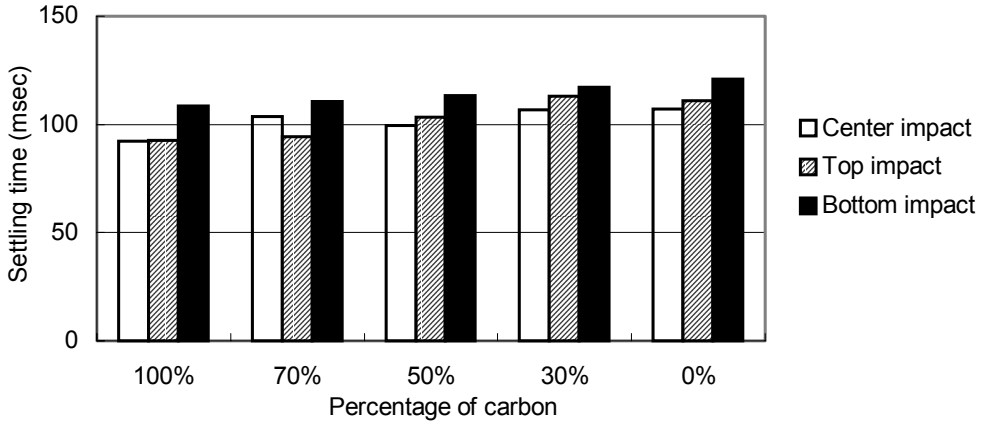

Figure 3 - Plots of the settling time with various tennis racket grip materials.

Table 3 The Mean and Standard Deviation of Maximum Amplitude with Various Tennis Racket Grip Material (unit : g)

Percentage of carbon Impact position	100%	70%	50%	30%	0%
Center impact	9.014	8.823	9.091	8.431	8.976
n=5	(0.144)	(0.389)	(0.273)	(0.624)	(0.181)
Top impact	7.171	7.819	7.980	7.874	8.439
n=5	(0.193)	(0.191)	(0.176)	(0.399)	(0.483)
Bottom impact	14.787	14.172	14.640	15.268	15.260
N=5	(0.455)	(0.454)	(0.339)	(0.420)	(0.562)

( ): standard deviation for five times per racket
*: mean statistically significant differences, p<.05

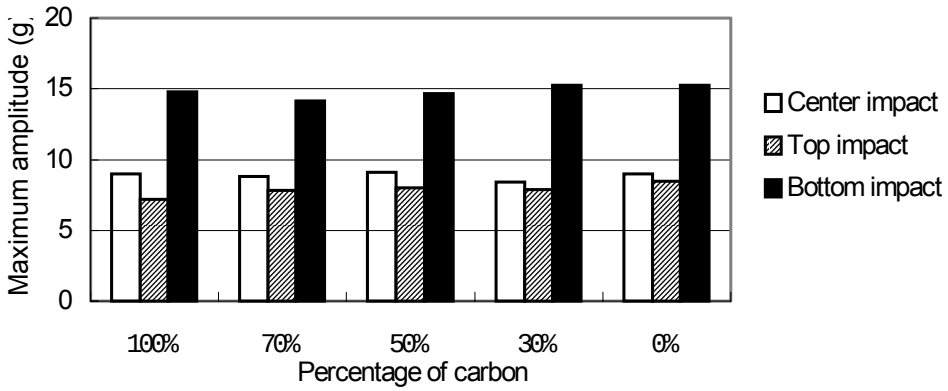

Figure 4 - Plots of the maximum amplitude with various tennis racket grip materials.

On the other hand, it was found that the maximum amplitude of five kinds of racket materials was not significantly different on center and off-center impact (Table 3). The reason might be these rackets had the same stiffness, weight, string tension and balance; moreover, these characters would not affect the value of maximum amplitude after impact.

Comparing the results with prior damping ratio (Chen, 1999) showed that the pure carbon fiber racket had a higher damping ratio on the center and off-center impact. And the damping ratio was decreased significantly as the content of glass fiber in the racket increased. Therefore, based on the vibrational analysis among the various material composition of tennis rackets, it was concluded that by increasing the content of glass fiber in the racket, it would be decreasing

the damping effect of the racket. In other words, it would increase the settling time of vibrational wave after impact.

From the results of performance control (Table 4), it showed that the pure carbon fiber racket had a higher value (0.785). And the performance control was decreased, as the content of glass fiber in the racket was increased (Figure 5). It was found that the vibrational force affect the subject's performance after several strikes. It increased the load in the tennis player's arm. Indirectly, this phenomenon would affect the athlete's ability in performance control and this study significantly confirmed these conclusions.

Table 4 The Mean and Standard Deviation of Performance Control with Various Tennis Racket Grip Material

Percentage of carbon	100%	70%	50%	30%	0%
Value of performance control* (n=12)	0.785	0.651	0.663	0.587	0.607
standard deviation	0.148	0.183	0.164	0.138	0.161

*: mean statistically significant differences, p<.05

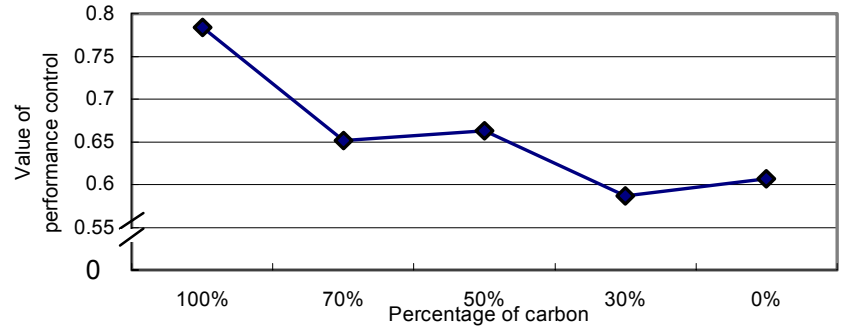

Figure 5 - Plots of the performance control with various tennis racket grip materials.

CONCLUSION: Five kinds of tennis rackets were tested in this study, and the impact of the tennis ball was set in the velocity of 4.09 m/s. The results indicated that the pure carbon fiber racket had a shorter settling time on the center and off-center impact. The degree of vibration didn't only depend on the maximum amplitude; other factors such as settling time and damping ratio should also be considered. Based on the vibrational analysis among the various material composite of tennis rackets, it was concluded that by increasing the content of glass fiber in the racket, the load in a tennis player's arm would increase. This study confirmed these conclusions.

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