

# THE EFFECT OF TENNIS RACQUET FLEXIBILITY ON REBOUND VELOCITY

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## INTRODUCTION

The tennis racquet has undergone drastic changes during the past two decades. Since 1970, racquet composition has evolved from wood to aluminum to fiberglass, graphite, and other synthetic composites. The size of the hitting surface has changed from the original 70 square inches, to averages of 95 to 110 square inches. While these changes were slow and originally met with a great deal of skepticism, a recent innovation in tennis racquet width has been quickly accepted by tennis manufacturers. The "wide body" racquet was introduced in 1988 with a frame 50% to 100% wider than conventional models. The wider frame increased racquet stiffness and manufacturers stated that this allowed greater velocity to be imparted to the ball with less energy expenditure by the individual (Wilson, 1992).

Several studies have previously evaluated the effect of racquet stiffness, along with varying string tensions, on rebound velocity. Baker and Wilson (1978) showed that the highest ball velocity ratios (outbound/inbound velocity) were obtained with flexible and average racquets strung at a tension of 50 pounds. These ratios were significantly higher than those of stiff racquets strung at the same tension. In contrast, Brody (1979) stated that a stiffer racquet would produce a higher velocity ratio, as less energy is lost in deforming the shaft of the racquet. Elliot (1982) conducted a study examining rebound velocity after a dynamic impact and found that at a string tension of 55 pounds, flexible and average racquets displayed higher velocity ratios than stiff racquets. Differences were not as evident at higher string tensions. All three studies concluded that lower string tensions resulted in higher rebound velocity due to an increase in string stretching, also known as the "trampoline effect." Others have confirmed this discovery (Bosworth, 1981; Leigh and Lu, 1992).

Due to the inconsistency of past results and recent changes in racquet design, the current investigation deemed warranted. This study was undertaken to determine if racquets contribute a "trampoline effect" similar to the strings, with more flexible racquets displaying higher rebound velocities. Specifically, the purpose of this study was to compare velocity ratios between racquets with a constant string tension and varying stiffness, and determine the influence of longitudinal racquet flexibility on ball velocity after impact.

## METHODOLOGY

The twelve racquets used in the study were divided into three stiffness classifications (flexible, average and stiff) by performing a longitudinal, static flexibility test suggested by a major tennis racquet manufacturer. The racquets were clamped horizontally and a five pound weight was hung from the tip of the racquet. Mean (sd) tip displacements were 0.54 ( $\pm$  0.05) cm for the flexible racquets, 0.38 ( $\pm$  0.03) cm for the average racquets, and 0.25 ( $\pm$  0.02) cm for the stiff racquets. All racquets were strung with nylon at a constant tension of 60 pounds. This tension was chosen as it was within

the range recommended by the manufacturers of the racquets tested. All racquets were classified as midsize, with a hitting surface of 95 square inches. Grip size was kept constant at four and one-half inches.

For testing, racquets were secured in a wooden clamp that extended from 22 cm below the lower edge of the oval frame to approximately five cm above the butt of the racquet. A Prince "Lobster" tennis ball machine was used to project eight new Wilson "U.S. Open Tournament Select" tennis balls from a distance of 2.5 m at the geometric center of each racquet. Mean ball velocity across all trials just prior to impact was calculated at  $33.0 \pm 4.0$  meters per second.

Each of the impacts was photographed with a 35mm camera using 400 speed film. The f-stop was set at 2.8 and exposure time was one second. The camera was placed two meters from the center of the racquet with its optical axis perpendicular to the flight of the ball. A reference measure was placed directly below the flight path of the ball. A stroboscopic light was set at 150 flashes per second and placed beside the camera. Each multiple exposure photograph displayed an image of six balls inbound and ten to fifteen balls outbound. Inbound balls were projected at an angle of approximately 5° above the horizontal to easily differentiate between inbound and outbound images. Three points around the perimeter of four ball images directly before and after racquet impact were digitized. A computer program was used to calculate the center of each ball image and subsequent pre/post impact velocities. For qualitative purposes, a high speed camera was set at 2000 fps and used to capture a ball to racquet impact for one racquet in each of the three stiffness categories. This camera was set up in a similar position as the 35 mm camera.

## RESULTS

A one-way analysis of variance indicated that differences were present ( $p < 0.05$ ) in mean ball velocity ratios between the three groups (see Table 1). A Tukey post hoc test revealed that the ball velocity ratio of the stiff racquets was significantly higher than those of the average and flexible groups, and the velocity ratio for the average group was significantly higher than that of the flexible group. A simple regression displayed a positive correlation ( $r = 0.92$ ) between racquet stiffness and ball velocity ratio (Figure 1).

Table 1. Mean ball velocity ratios for twelve racquets.

Racquet Type	Mean Velocity Ratios (8 trials)				Mean	SD
Flexible (n=4)	0.354	0.367	0.385	0.388	0.374*	0.016
Average (n=4)	0.392	0.407	0.411	0.419	0.407*	0.011
Stiff (n=4)	0.429	0.441	0.447	0.476	0.448*	0.020

\*  $p < .05$

An observation from the high speed film may offer an indication as to why stiffer racquets generated greater rebound velocity. In extreme slow motion, all racquets could be seen deflecting back upon ball impact, with stiffer racquets displaying less initial deflection than more flexible ones. The racquets continued deflecting back for 8-12 ms after the ball was propelled forward by the strings. Thus, the strings were able to apply force back to the ball after impact, while the racquet, due to less resiliency, was unable to transfer momentum back to the ball. Therefore, a stiffer frame bent less upon impact, absorbed less energy than a more flexible one, and resulted in a higher rebound velocity.

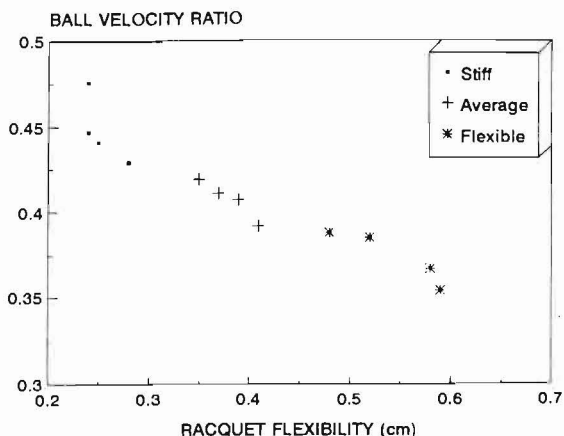


Figure 1. The relationship between ball velocity ratio (outbound/inbound) and tennis racquet flexibility.

## CONCLUSIONS

This investigation was undertaken to examine the relationship between tennis racquet stiffness and rebound velocity. Recent statements made by racquet manufacturers suggested that stiffer frames produce higher rebound velocity (Wilson, 1992). The results of this study showed that racquet stiffness was positively correlated to rebound velocity.

However, these results are not in agreement with those from previous, similar studies. A close examination reveals possible explanations. First, previous studies (Baker and Wilson, 1978; Elliot, 1982) placed the clamped racquet between two rubber pads, possibly to simulate a racquet held in the human hand. In this case, the pads would absorb a great deal of energy, reducing rebound velocity. The purpose of this study was to measure qualities of the racquet alone, and it was clamped in direct contact with wooden blocks. Second, the current study revealed a higher range of velocity ratios (0.35 - 0.48) than the Baker and Wilson (1978) study (0.30 - 0.36). This indicates that there is a greater variability in racquet stiffness in today's market and differences in rebound velocity may be more pronounced.

## REFERENCES

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