Tennis Racket Impact Point and Coefficient of Restitution

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Abstract

The relationship between the contact point of a ball hitting a tennis racket and the coefficient of restitution (COR) of the ball was investigated. A tennis ball was launched onto various points on the head of a clamped tennis racket. The impact was recorded from the side and behind using high-speed cameras to determine the contact point and COR. The COR was calculated by dividing the rebound velocity by its impact velocity, measured using Logger Pro video analysis. The results showed the COR increasing in value as the contact point approached the central line and with the highest values on the line towards the handle. This study provides insights into the physics of tennis rackets and can be used to inform coaching.

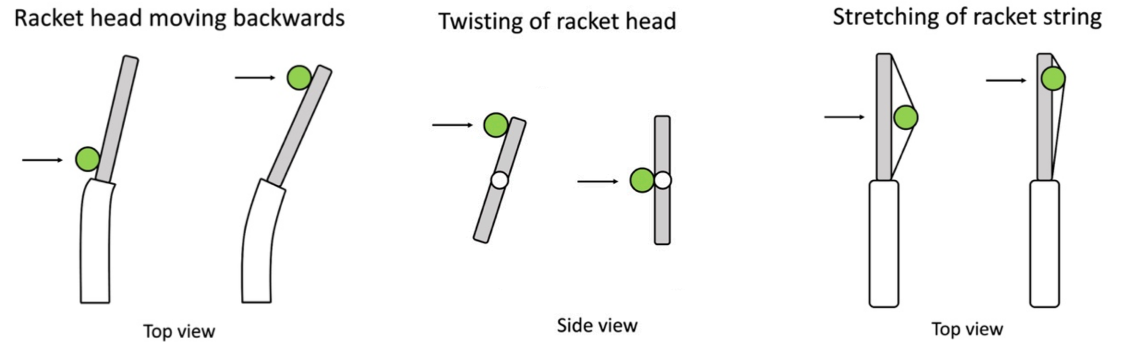
Keywords: tennis racket, impact position, coefficient of restitution

I. INTRODUCTION

Tennis is a popular sport that requires a combination of skill, technique, and physical ability. Professional tennis players require the ability to control the speed at which the tennis ball leaves the racket. An important factor in rebound speed is the contact position of the ball on the racket head. In this research, we will be focusing on the relationship between the point where the tennis ball impacts the head of a clamped racket and the coefficient of restitution (COR) of the bounce. The COR of a ball bouncing off the racket is defined as the ratio of bounce speed and impact speed.[1]

There have been studies on the effect of impact speed on the COR of a tennis ball.[1,2] One study showed that there is a negative linear relationship between the COR and the impact velocity of the ball on a clamped head for velocities between 13 m/s and 36 m/s.[2] No published studies were found investigating the relationship between the COR and the impact point on a tennis racket head.

Several factors contribute to the loss of energy when a tennis ball bounces off a racket. As shown in figure 1, there are three main ways in which the racket deforms during an impact, resulting in energy loss. Firstly, figure 1(a), energy loss is directly dependent on the amount that the handle is bent backwards during a hit. It was observed that a ball hitting near the handle will deform the handle less than when it hits near the end of the racket. Impacts near the base of the racket head, near the handle, has a smaller length of the cantilever, therefore, the deformation of the racket handle will be less, resulting in less energy loss. Similarly, impact further from the handle causes the racket head to deform more leading to expected higher energy loss and lower COR.



(a) (b) (c)

Figure 1. Factors that contribute to deformation during impact of a tennis ball at different positions on the racket head.

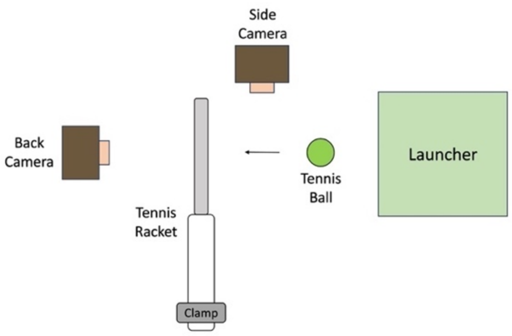


Figure 2. Experimental setup

Secondly, contact along the central line of the head will cause no torsional force on the head, meaning the racket head will not twist. A ball which hits above or below the center line of the head will rotate the handle, as seen in figure 1(b), resulting in greater energy loss.

Lastly, energy loss is directly dependent on the relative deformation of the strings. Impact in the middle of the head produces the least relative stretching, as the strings are the longest along both axes of the head, as shown in figure 1(c). A ball hitting near the edge of the racket will cause higher relative deformation of the strings on the side nearest the edge, leading to higher energy loss.

While the relative energy loss due to each of these three factors is unknown, it is likely that the bending and twisting of the handle will lead to more energy loss than the stretching of the strings. Therefore, it is expected that the highest COR will be along the center line of the racket and the COR will increase as the contact point approaches the handle at the base of the racket head, since the deformation of the handle decreases as the impact point approaches the handle.

II. METHODS

The racket was fixed horizontally with clamps, and the tennis ball launcher was placed 0.3 meters in front of the racket, as shown in figure 2. Three newly opened competition standard tennis balls from Duncan Fort were used. Six trials were conducted for each of the eleven target positions shown in figure 6. The target areas were all approximate, as the direction that the balls were projected from the launcher was highly variable. The side camera, a high-speed camera set at 480 fps, was positioned parallel to the height at which the balls were launched to record the complete impact and bounce of the ball. The back camera was a mobile phone set at 60 fps.

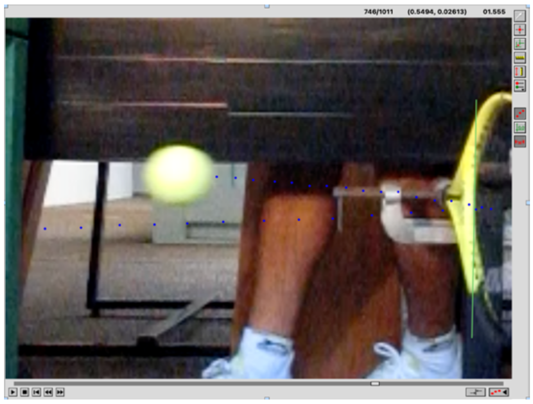


Figure 3. Tracking the position of the ball over time as it bounced off the racket. The blue dots represent the position of the ball at each frame.

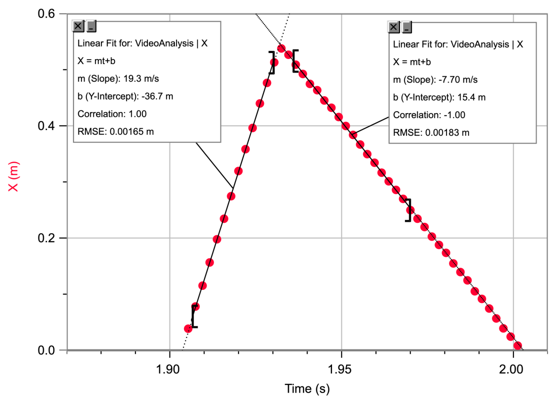


Figure 4. The graph from the video analysis shown in figure 3 showing incoming and outgoing velocities.

Figure 5. Frame-capture from the back camera used to determine the impact point of the ball.

For each trial, one ball was loaded into the launcher, and the process of the ball coming in, hitting the racket, and rebounding out was recorded by both cameras. The resulting recordings were analyzed using Logger Pro video analysis software, as shown in figure 3. The inbound and rebound velocity was determined from the gradients of the lines fit to the position-time graph, as shown in figure 4. The horizontal and vertical distance of the ball impact point from the center of the racket was determined using a frame-capture from the back camera, as shown in figure 5.

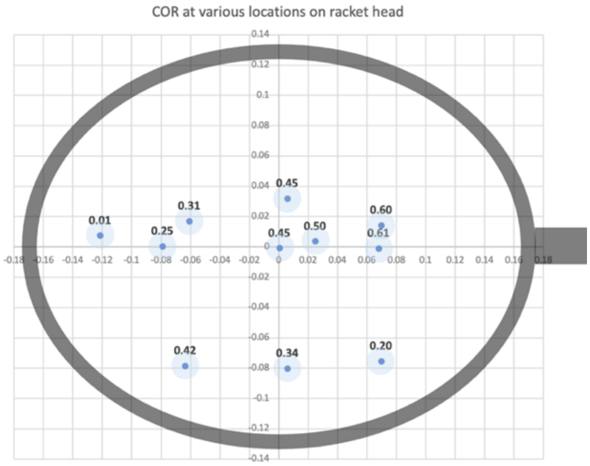


Figure 6. The COR values at the tested impact locations. The head is shown in gray with the handle on the right. The blue shaded circles indicate impact point variability for each position.

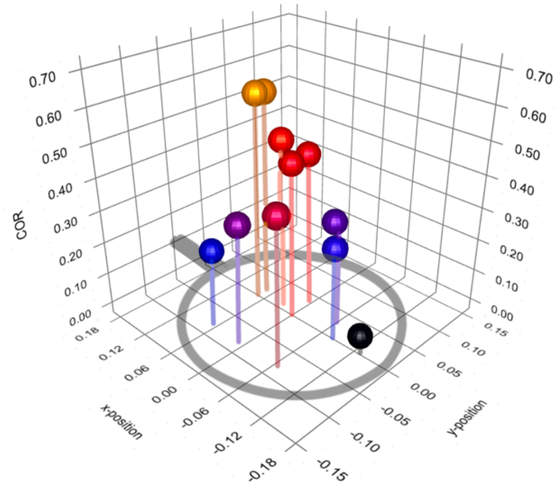


Figure 7. A 3-D graph showing the data presented in figure 6. The head of the racket is shown in gray, with the handle on the far side.

III. RESULTS AND DISUSSION

The COR of the ball varied with the impact location as shown in figure 6. While the difficulty of controlling the launch direction from the launcher resulted in a non-symmetric distribution of the points, the general trends are still clear. The two major factors affecting energy loss discussed in the introduction were twisting of the racket due to the ball hitting off the central line, and the increased backward bending of the handle as the ball impacts farther from the handle. Both of these trends are clearly shown in figure 6. For any given distance from the handle the COR tends to decrease as the ball impacts farther from the central line of the head. Along the central line of the racket, the COR ranges from 0.01 at the tested impact point farthest from the handle up to 0.61 at the point tested closest to the handle.

Further research is suggested with a more accurate ball launcher able to precisely shoot the ball, so that a complete symmetric map of the COR with more points over the entire head of the racket could be made. Further research is also suggested to study how the impact velocity and impact angle of the ball affect the deformation of the strings and handle for impact locations across the head of the racket.[3] Exploring these factors would aid researchers in gaining a deeper understanding of the mechanics of a tennis racket and identify new areas for improvement in racket design.

IV. CONCLUSION

It was shown that the COR increases as the impact point approaches the handle of the racket, likely due to decreased bending and less energy loss in the racket handle. The COR was also shown to decrease as distance of the impact point from the central line of the racket head increased, due to increased torque and the resulting twisting of the handle.

V. REFERENCES

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