

Coefficient of Restitution of Badminton Smashes

Tee Monsereenusorn

*International School Bangkok,
39/7 Samakee Rd, Pakkret,
Nonthaburi, 11120, Thailand
Email: tmonsereenusorn@gmail.com*

Abstract

Badminton smashes were recorded and analyzed at high speed, measuring the velocities of the shuttlecock and racquet head to determine the relationship between initial impact velocity and the coefficient of restitution. It was found that the coefficient of restitution follows a negative linear relationship with impact velocity. Such a relationship suggests players can most efficiently apply force at lower smash velocities.

Keywords: badminton, coefficient of restitution, badminton smash

I. INTRODUCTION

In badminton, the smash is a shot in which a player pivots the racquet head rapidly to strike the shuttlecock at a downwards angle with great velocity. The coefficient of restitution (COR) measures the ratio of the final to initial velocity of the two objects in the collision, represented by the equation,

$$COR = \frac{v_b - v_a}{u_a - u_b} \quad (1)$$

where v and u represent the final and initial velocities for objects a and b , respectively. The two objects involved during the badminton smash are the racquet head and the shuttlecock.

Previous work describes the ratio of impact velocity and shuttlecock exit velocity for the badminton dropshot (low impact velocities), where the ratio was shown to be constant.¹ This paper investigates the changes in COR for badminton smashes (greater impact velocities than dropshots). Understanding the relationship between impact velocity and resulting COR can enable better decisions about the velocity with which to strike the shuttlecock, which can directly affect the performance of the athlete.

During a badminton smash, there are several aspects of energy loss that can reduce the total kinetic energy of the system. The impact deformation of a badminton shuttlecock, shown in Figure 1, was previously studied by Lin et al.² While other factors

affecting energy loss in a badminton smash have not been studied, it has been shown that during a collision of a tennis ball and a tennis racquet, the energy loss due to the impact deformation of the ball increases exponentially with the magnitude of impulse on the ball.³ It has also been shown that the largest source of energy loss in tennis is the recoil motion of the racquet, the vibration of the racquet frame after impact, and the vibration of the strings.³

Assuming that the loss of energy during a badminton smash is similar to that of hitting a tennis ball, the energy loss is expected to increase with increasing impulse applied to the shuttlecock, resulting in decreased COR. Given that badminton smashes used in normal play are at relatively high speeds, with a narrow range of speeds, it is proposed that in badminton smashes, the COR follows a negative, linear relationship with the impact velocity:

$$COR = -a \cdot u_r + b \quad (2)$$

where u_r is the initial racquet head velocity, and $-a$ is the rate of change of COR as a function of u_r .



Figure 1. This series of images depicts the impact deformation of a Kason shuttlecock.²

II. METHODS

A Casio EX-F1 camera was set up 1.5 meters above the ground and 4.0 meters away from the collision, as shown in Figure 2. A Yonex[®] Aerosensa-20 shuttlecock (5.19 ± 0.01 g) was tossed vertically upwards in front of a wall and hit during its descent. The shuttlecock was smashed horizontally, parallel to the wall, by a Yonex[®] Nanoray 300 racquet (84.00 ± 0.05 g) with Yonex[®] BG-66 force strings (tension of 22.8 ± 1.2 lbs).

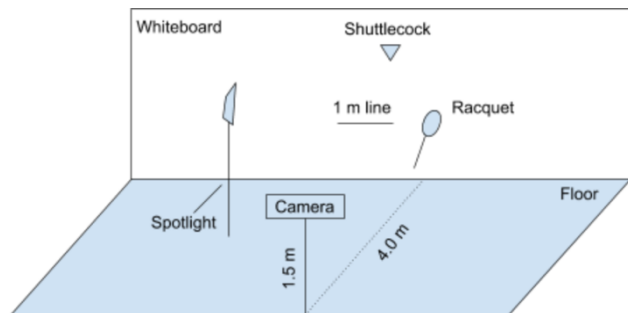


Figure 2. Experimental Setup.

Logger Pro[®] Video Analysis was used to calculate the COR of 30 smashes by determining the velocities of each component before and after the collision. Only trials in which the cork head of the shuttlecock struck approximately the middle of the racquet were analyzed. The video axes were rotated to align with the direction of motion of the component being measured.

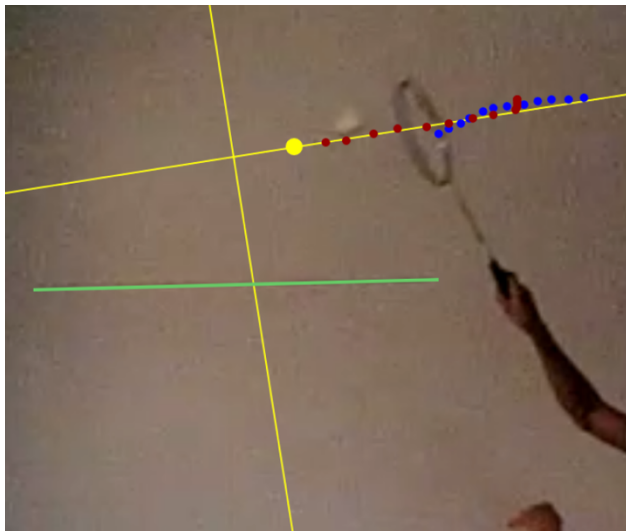


Figure 3. Sample frame-by-frame plotting of points. Blue data points are plotted in the center of the racquet face while red data points are plotted at the head of the shuttlecock.

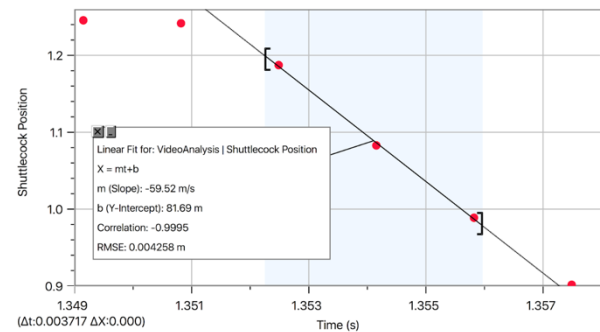


Figure 4. Sample position-time graph yielding the shuttlecock velocity of 59 m/s after impact.

The positions of the racquet head and shuttle cock were tracked in the video, as shown in Figure 3. The gradient of three data points just before and after the collision of the position-time graph generated by Logger Pro[®] was then used to determine the velocities of each component, as shown in Figure 4.

III. RESULTS AND DISCUSSION

The relationship between COR and the initial racquet velocity is shown in Figure 5. As the velocity of the racquet head increases over a normal range of smash impact velocities, the COR decreases:

$$COR = (-0.013 \pm 0.005)u_r + (1.1 \pm 0.2) \quad (3)$$

The trend is in accordance with existing theory, as greater impact velocities apply more impulse on the shuttlecock, resulting in a greater deformation and energy loss.

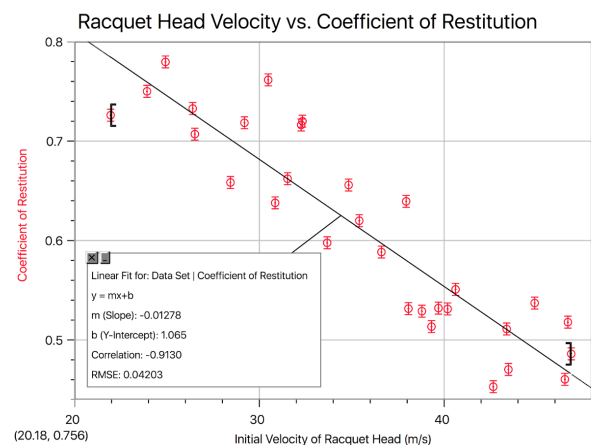


Figure 5. The initial velocity of the racquet head against the COR of the collision, showing a negative linear relationship.

Equation 3 predicts a COR of 1.1 at 0 ms^{-1} impact velocity, and a COR of 0 at 85 ms^{-1} , which is unlikely to be correct. However, it is not expected that this model is applicable at impact velocities outside the investigated range of 20 ms^{-1} to 50 ms^{-1} as the nature of the impact would likely be significantly different at very low and very high impact velocities. Also, the variance of the data is high as factors such as impact racquet angle, shuttlecock angle or impact point will inevitably be variable in real play, thus the high variability indicates the range of the COR in real life play.

A limitation in this study was that it may not be accurately modeling a real-life badminton smash. For example, the method of tossing the shuttlecock such that it travels back down vertically does not approximate the flight of a birdie in real play, which normally collides with the racquet at an angle closer to perpendicular.

It is suggested that an experimental technique be developed so that the point of contact of the shuttlecock on the racquet can be controlled. The relationship between the COR and the impact location on the racquet could then be studied. This is especially important as players often strike the shuttlecock in different regions of the string bed.

IV. CONCLUSION

Over the range of badminton smash velocities investigated, the relationship between initial impact velocity and the COR of the collision follows a negative linear relationship. It was shown that on average, the coefficient of restitution dropped by 0.013 for every 1 ms^{-1} increase in initial impact velocity.

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