ISB Journal of Science, Vol. 8, Iss. 1 Jan-Dec, 2014
http://www.isjos.org

Spin Rate of a Racquetball Due To Angular Impact

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Abstract

The relationship between the impact angle of a racquetball and the resulting angular velocity of the ball was investigated. Impact angles ranging from 0° to 80° were tested. The ball was dropped at constant speed on a plywood board that could be angled and the impact was filmed at 600 fps. The video was then analyzed to determine the angular velocity of the ball after the bounce. It was found that there is a proportional relationship between the incoming impact angle (θ) and angular velocity (ω) of the racquetball, for angles up to 50°, indicating that the ball did not slip during impact at these angles.

Introduction

Racquetball is played with a hollow rubber ball and racquets. In order to achieve shots that force your opponent to run from side to side and from front to back the ball must be hit at an angle. When the ball impacts the wall at an angle, it begins to spin, due to the friction between the ball and the surface. At angles near normal incidence, the friction is expected to be great enough to cause the ball to stick to the surface during the bounce, while at high impact angles (see figure 1), the ball may begin to slip during the bounce.[1] Knowing whether the racquetball sticks or slips during the bounce is crucial in predicting its trajectory and spin rate. [2] Thus, this research set out to determine how the impact angle affects the spin of the ball, and the angle at which the ball begins to slip.

As shown in figure 1, when a racquetball impacts a surface, the center of mass (*CM*) of the ball continues to move parallel to the floor during the time it is in contact with the surface. Thus, due to friction (F_f) acting opposite to the motion of the ball, a torque (ω) results, causing the ball to spin. In the case of a ball impacting a surface at an angle without any initial spin, as seen in figure 1, the lateral component of its impact velocity (V_x) is proportional to the sine of its impact angle ($sin\theta_{in}$). During contact, the 'skin' of the ball stops due to friction (F_f), while the center of mass continues to move laterally.[3] If the skin of the ball remains stationary with respect to the impact surface at the end of the time of impact then the angular velocity is,

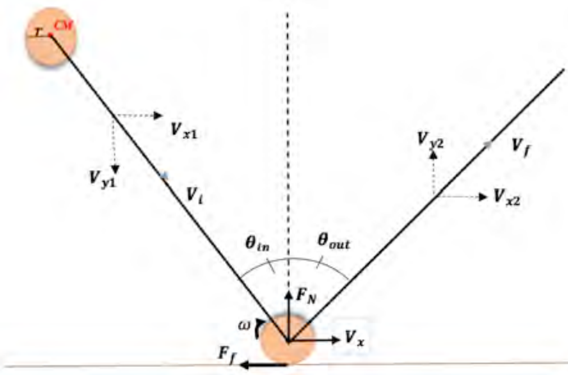


Figure 1 Analysis of the ball during the bounce.

$$\omega = \frac{V_{x2}}{r} \qquad \text{Equation 1}$$

Considering the fact that both linear and angular momentum are conserved in the impact of the ball with the surface the change in the lateral velocity can be represented by, [4]

$$\Delta V_{x2} = \frac{3}{5}(V_{x1}) = \frac{3}{5}\left[\frac{(V_i \sin\theta_{in})}{r}\right]$$

Therefore,

$$\omega = \frac{3}{5}\left[\frac{(V_i \sin\theta_{in})}{r}\right], \qquad \text{Equation 2}$$

As long as the ball does not slip on the impact surface. At low impact angles (close to perpendicular), the frictional force between the surface and the skin of the ball is expected to be great enough to cause the ball to stick to the surface during the bounce, and equation 2 applies.[5] However, at greater impact angles, the force required to get the ball spinning at ω is expected to exceed the maximum frictional force, and the ball will slip during the bounce.[3] This will reduce its spin rate and increase the horizontal component of its bounce velocity (v_{x2}), which will result in a change in its bounce trajectory.

In this research, the impact angle at which slippage occurs will be determined for a racquetball being dropped from a fixed height onto an inclinable surface at different angles. As described above, the point of slippage for a racquetball is expected to occur at impact angles where the force needed to accelerate the ball up to the expected angular velocity exceeds the maximum frictional force. Determining this angle will enable racquetball players to understand and predict the trajectory of the ball at all impact angles.

Methods

An inclined plane was adjusted to angles ranging from 0° to 80°, using wooden wedges. A regulation racquetball was marked similar in fashion to a basketball as show in figure 2, allowing the ball to be tracked in a data analysis program. The ball was placed at a fixed drop height (70.3$\pm$.1 cm) above a predetermined impact point prior to every trial. A high-speed camera was set up such that it was perpendicular to the drop path of the ball and spotlights were used to illuminate the setup. With the experimental setup in place, the ball was released and its impact filmed at 600 frames per second. This process was repeated for 8 different angles ranging from 0° to 80°.

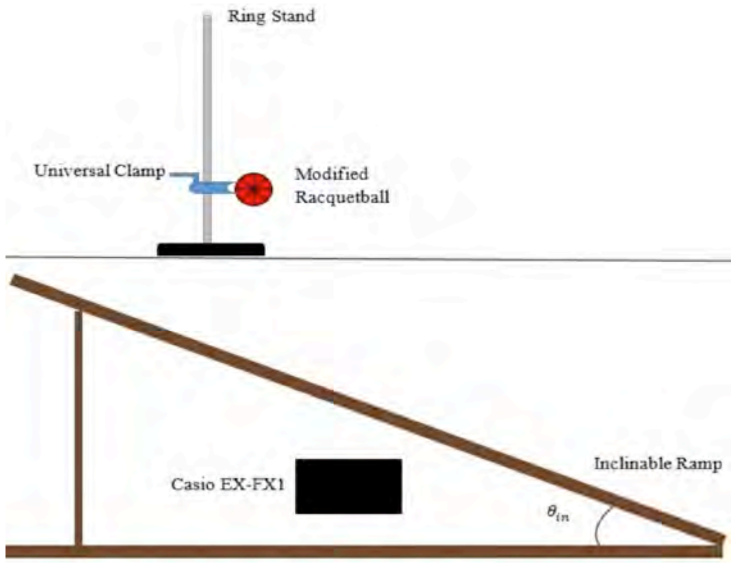
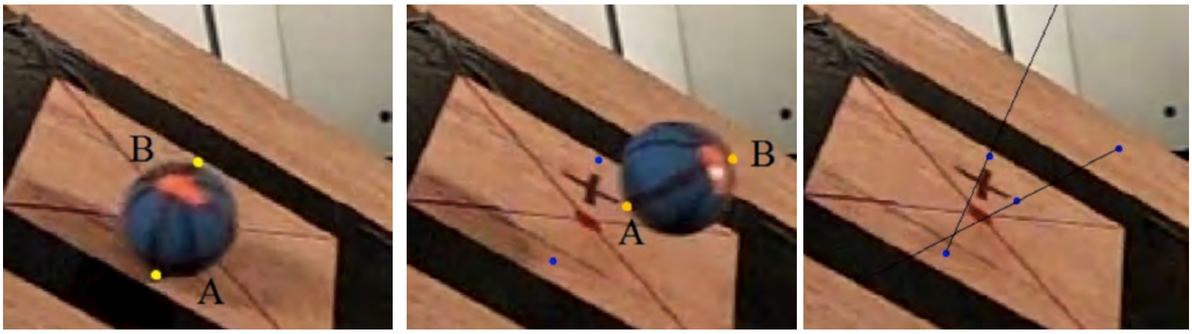


Figure 2 The experimental setup used.

As seen in figure 3 below, the angular velocity of the ball was calculated by tracking the ball in a video analysis program. In figure 3a, two points were placed on each end of the equatorial line on the ball at impact. An additional two points were placed on the ball after 10 frames had passed, as shown in figure 3b, the second image. Finally, the angle created at the point of intersection, seen in figure 3c, is the angular displacement of the ball within the time of the 10 frames, which was used to calculate the angular velocity of the ball.



Figures 3a, 3b, 3c The video was analysed to determine the angular velocity of the ball after impact.

Results and Discussion

As seen in figure 4, the relationship between the impact angle and the angular velocity of the racquetball is proportional up to 50°. At an impact angle of 60° the racquetball begins to slip, and by 80°, significant slipping is occurring, as the spin rate is significantly lower than expected. The relationship between spin rate and sine of the impact angle can be expressed as,

$$\omega = 81\ (\pm 10\ s^{-1})\sin\theta. \quad \text{Equation 5}$$

Using the impact velocity and the radius of the racquetball in equation 2 resulted in a predicted proportionality constant of 80 s^{-1}. This matches the results shown in equation 5, and strongly supports the conclusion that the racquet ball skin is gripping the surface at impact angles up to 50°.

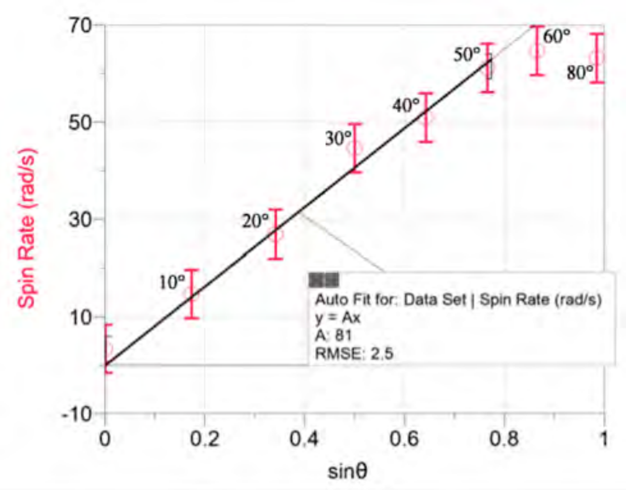


Figure 4 The proportional relationship between impact angle and the angular velocity of a ball with a proportionality constant of 81. Above 50° the ball begins to slip during impact.

Since in practical play the ball very rarely impacts at an angle above 60°, it seems that it would be realistic for a player to assume that the ball will always stick and that the ball's spin and its bounce trajectory will follow a predictable pattern. But, as can be seen from figure 4, even if the ball impacts at an angle of 80°, there is a reduction in spin of only around 10%, implying that the effect on the trajectory will be minimal.

There were several aspects of this research that reduce the confidence with which the conclusions can be applied to practical racquetball play. Firstly, the surface used was wood, which does not have the same friction coefficient as a normal court. Another issue was that rather than the ball being launched at different angles onto a horizontal surface, the ball was dropped onto a surface that was inclined to the different angles. Finally, the constant speed of impact studied was much lower than the range of speeds experienced in typical play. Thus, it is possible that the conclusions of this research may not correctly model the behavior of a racquetball during normal play.

It is suggested that methods be developed to study the impact behavior of a racquetball under typical playing conditions. This might be done using a variable-speed ball launcher to project balls at various angles onto a racquetball court floor and walls. It is suggested that further testing of angles between 50° and 80° be conducted, so that the point of slippage can be more precisely determined. Finally, further research using a force plate and a high speed camera for a ball striking a vertical plane may lead to a better understanding of the dynamics of the ball during impact.

Conclusion

It has been shown that when a racquetball impacts a surface at an angle of 50° or less, the skin of the ball sticks to the surface during impact, resulting in a proportional relationship between the sine of the impact angle and the resulting spin rate of the ball. At impact angles above 50°, the ball begins to slip, resulting in reduced slipping and an altered trajectory. Since the ball rarely impacts above 60° during normal play, a racquetball player can generally assume that the spin rate and bounce trajectory will be that predicted for a non-slipping impact, and adjust his play accordingly.

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