Where on the Head Should You Hit the Ball for Maximum Power?

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ABSTRACT

This article discusses where on the head to hit the ball to get maximum "power" for various ratios of incoming ball speed, V_{inc}, to racket head speed, V_R, and for different types of swings. It then shows the advantage of hitting the ball at that location.

INTRODUCTION

There are three "Sweet Spots" on a tennis racket - locations where it feels good to hit the ball. They are the node (minimum vibration point), the center of percussion (minimum shock or jar point) and the maximum power point (highest ball rebound speed). The location of the node and center of percussion points of the racket are fixed by the physical parameters of the frame (length, balance, moment of inertia, flexibility, etc). They are located near the center of the strung area and are usually very close to each other, so if you hit one, you generally hit the other. The maximum power point location is also determined by these same physical parameters and in addition, the style of the stroke and the incoming ball speed. Where the location of the node and center of percussion can be determined in the laboratory, the location of the maximum power point can, and does vary from shot to shot and player to player.

LOCATION OF THE POWER SPOT

When rackets are tested for power in the laboratory, balls are fired at a freely suspended racket at rest and the ratio of ball rebound speed to incident ball speed is determined for various impact points on the head. This ratio, ($V_{rebound}/V_{incident}$), is called the apparent coefficient of restitution (ACOR)[1]. The term "apparent" is used since the recoil speed of the racket is neglected. The value of the ACOR tends to maximize near the balance point (center of mass) of the racket and falls off as the ball impact location moves away from balance point toward the tip. The reason for this variation comes from the basic physics of the interaction. When a ball impacts at the center of mass, no energy goes into racket rotation, since the racket just recoils and does not rotate. The further the ball impact point is from the center of mass, the greater is the impulsive torque tending to rotate the racket about its center. As more energy goes into racket rotation, less goes into the ball's rebound, so the ACOR decreases. For a free racket at rest, this leads to lower values of ACOR as the impact point moves away from the balance point and toward the tip of the frame. The value of ACOR as a function of ball impact location for a typical tennis racket is shown in figure 1[2].

If, when you swing at the ball, the racket were translated (straight line motion only) the maximum ACOR point would be the maximum power location since all points in the racket are moving with the same speed. But a racket is swung in an arc, not translated in a straight line, so the tip has a higher velocity than the throat. This moves the location of the maximum power point higher up on the head. In terms of the incident ball speed (V_{inc}), the racket head speed (V_{raq}) and the ACOR, the speed of the struck ball (V_H) is given by [3]

$$V_H = ACOR \times V_{inc} + (1 + ACOR) \times V_R$$

Let $V_{inc} = k \times V_R$ where k = 0 is a serve
k = 1 is a typical groundstroke
k = 2 is a volley

$$V_H = ACOR \times k \times V_R + (1 + ACOR) \times V_R$$

$$V_H = ACOR \times V_R \times (k + 1) + V_R$$

Let $V_R = \omega \times R$ where R is the distance from the effective swing pivot point to the ball impact point, and ω is the angular velocity of the swing.

$$V_H = ACOR \times \omega \times R \times (k + 1) + \omega \times R$$

$$V_H / \omega = ACOR \times R \times (k + 1) + R$$

Assuming ω is constant and using ACOR, as given in figure 1, it is possible to determine the outgoing ball speed for various values of k. The results of such a calculation are shown in the figure 2. It can be seen that as the ratio of incident ball speed to racket head speed increases, the maximum power point on the racket head moves away from the tip and toward the throat. ***Therefore, it is recommended that when playing on fast courts (such as grass), the ball should be hit a little closer to the throat. When playing on slow courts (such as clay), the ball should be hit a little closer to the racket's tip. It is also clear from this argument that a serve should be hit closer to the tip and a volley, closer to the throat of the racket.***

It is also possible to see how the location of maximum power point shifts as the stroke is modified by changing the location of the effective pivot point of the swing. Figure 3 shows that as this pivot point moves down the arm toward the hand, the location of maximum power moves toward the racket's tip. ***Since the serve is hit*** *with a relatively flexible wrist and the volley with a firm wrist, this further reinforces the argument to hit the serve closer to the tip and the volley closer to the throat.*

ADVANTAGES OF HITTING POWER SPOT

There are two advantages in hitting the ball at the maximum power location on the head. One advantage is obvious. To get the ball speed you desire, you don't have to swing the racket as hard. This means you will probably have more control over the racket head and leads to less unforced errors. The second advantage of aiming to hit the ball at the maximum power point is more subtle. It can be shown that by aiming at the power point, you will reduce your chances of making an error where the ball sails long over the baseline.

The trajectory of a ball off your racket is uniquely specified by the ball's initial speed, angle, height, and spin. Holding the angle, height and spin constant, there is a window or allowable tolerance in the ball's initial speed that permits the ball to clear the net and land on or inside the baseline. A good player does not take advantage of this entire window, since short shots (bouncing near the service box) tend to give the opponent an easy shot to return for a winner. The object is to have the ball land close to the opponent's baseline, yet never go over it. This strategy reduces the window or tolerance with respect to ball speed off the racket. Having now found the location of the power spot on the racket head, the argument will be made as to the advantages of hitting the ball at that location to implement that strategy.

Let us assume you aim to hit the ball at a location that is 0.25 meters from the tip of the frame and your racket head speed is comparable to the incoming ball speed (V_{inc}/V_{raq} = 1 in figure 2). Assume the ball leaves the strings with a speed of 70 mph and you set the racket head angle to give you good depth (middle trajectory in figure 4). Figure 2 shows that if you do not hit the ball at exactly the aiming location on the head (0.25 m), then the ball will come off the strings with a greater or lower speed. The result of this is shown by the other two (65 and 75 mph) trajectories in figure 4. The result is that ball striking the racket somewhat closer to the tip than the 0.25 m mark will end up going long, resulting in a loss of the point. This problem can be solved by reducing the racket head speed (and still aiming to hit at the 0.25 m location) so that shots hit further out on the head (leading to higher ball speeds) now land in the court. The disadvantage of this correction is that the average ball now will lands short, giving your opponent an easy shot to return.

Now let us go through the same process, only aiming to hit the ball at the peak power location (a distance of 0.18 m from the tip) and adjusting the racket head speed to produce a ball leaving the strings at 70 mph. This ball's trajectory (as shown in figure 5) will land deep in the court and be a good, aggressive shot. If you miss the maximum power location by striking the ball closer to the tip or closer to the throat, the ball will come off the strings with a lower speed (65 and 66 mph), as can be seen from figure 2. The trajectories of the other two lower speeds balls are also shown in figure 5. Both of these land somewhat shorter, but neither leads to an error when the ball is slightly miss-hit.

The result is that by aiming to strike the ball at the maximum power location on the head, you can get a deep, aggressive shot and reduce the number of unforced errors at the same time.

FIGURES

Figure 1. Apparent Coefficient of Restitution (ACOR) for a free racket as a function of ball impact distance from the racket tip.

Figure 2. Speed of struck ball versus location of the ball impact point on the racket head for a ratio of incident ball velocity to the racket head velocity, k = 0, 1.0, and 2.0.

Figure 3. Speed of struck ball versus location of the ball impact point on the racket head for two different types of swing. One type of swing has an effective pivot 0.1 m from the butt end and the other has an effective pivot point 0.3 m from the butt end.

Figure 4. Trajectories of balls hit at an initial angle of 6.5 degrees and 65, 70 and 75 mph.

Figure 5. Trajectories of balls hit at an initial angle of 6.5 degrees and 65, 66 and 70 mph.

REFERENCES

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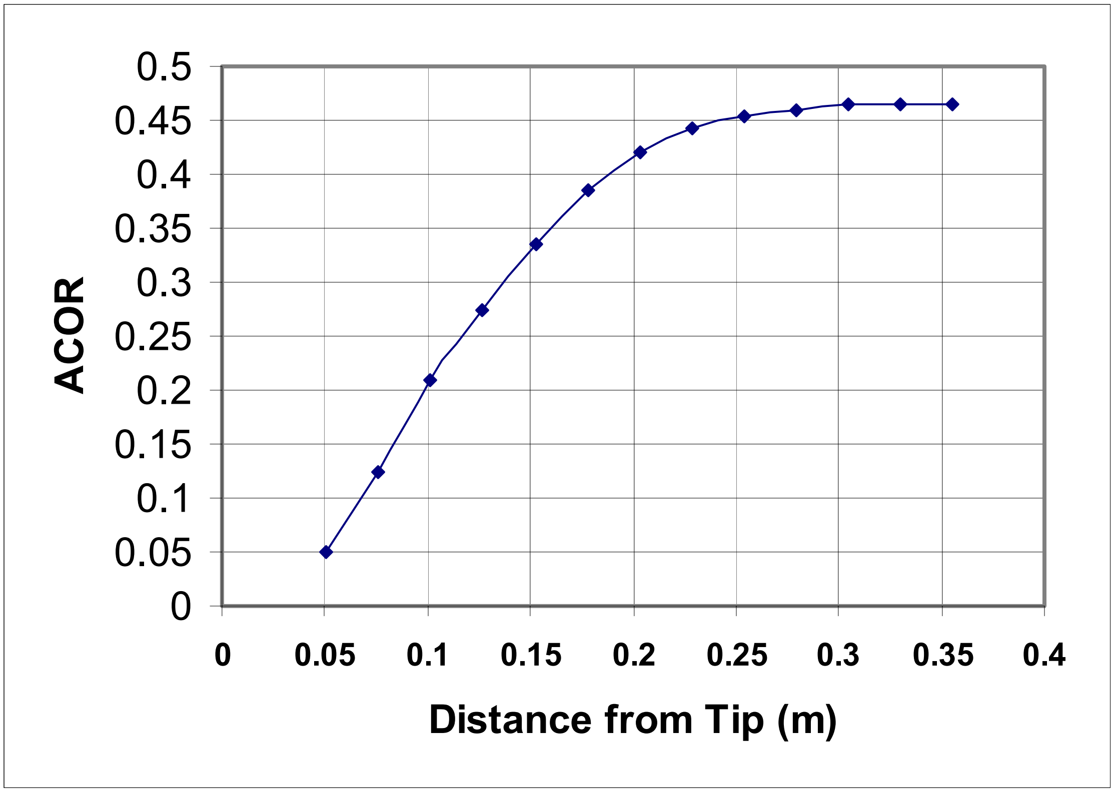
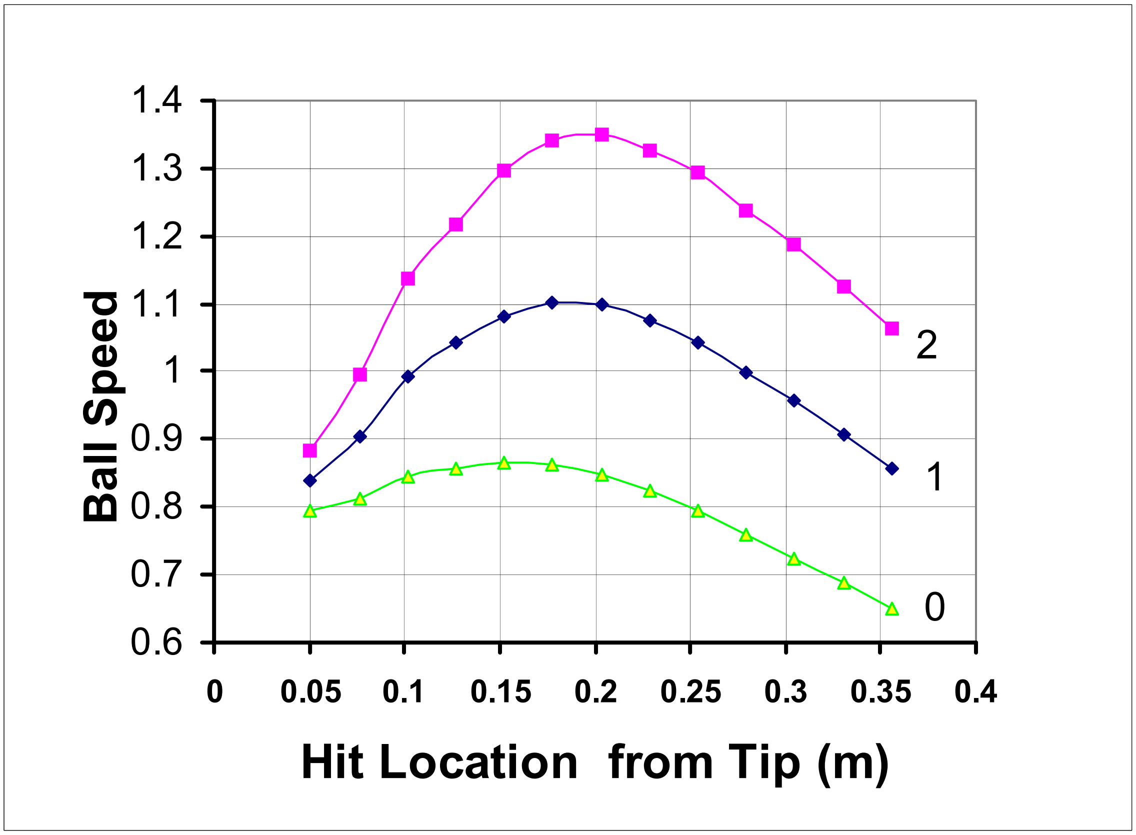
2.) Brody, Cross and Lindsey, 2002, "The Physics and Technology of Tennis" Racquet Tech Publishing, Solana Beach, CA pg. 122

3.) Brody, H. "How would a physicist design a tennis racket?" Physics Today, 48, pg 26, 1995



ACOR
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Distance from Tip (m)

Figure 1



1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
Ball Speed
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Hit Location from Tip (m)
2
1
0

Figure 2

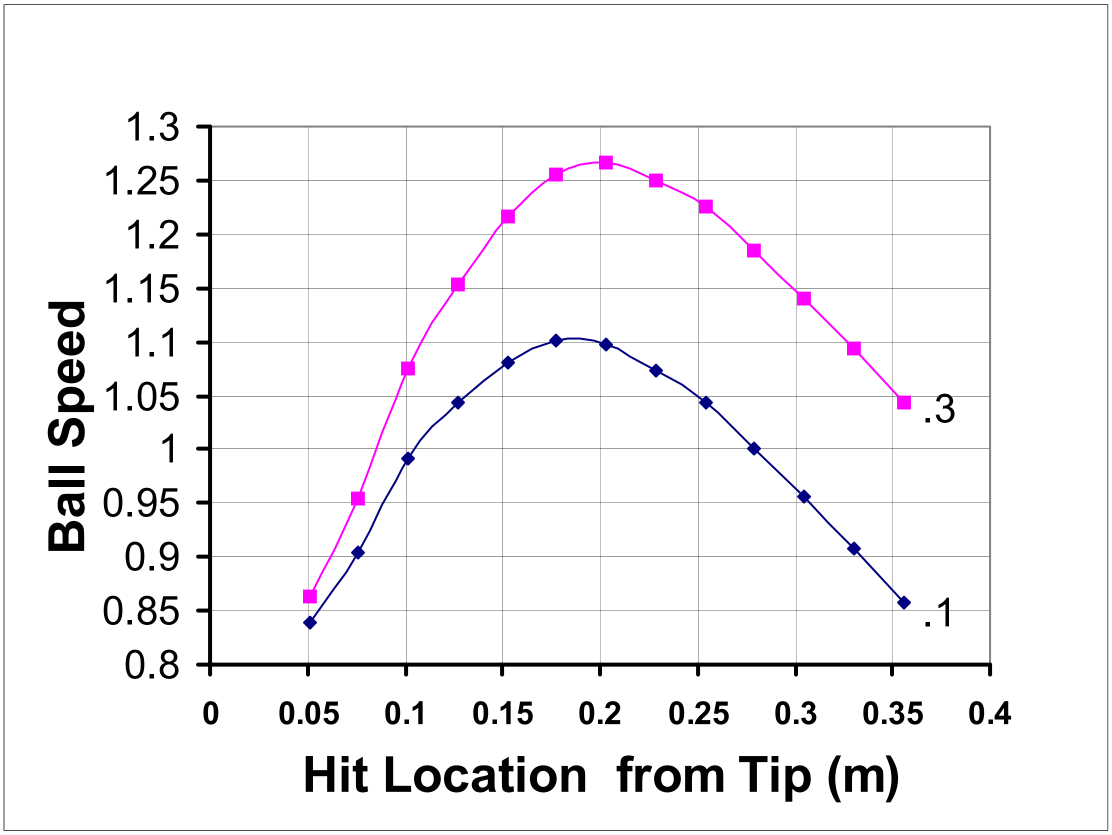

1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
Ball Speed
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Hit Location from Tip (m)
.3
.1

Figure 3

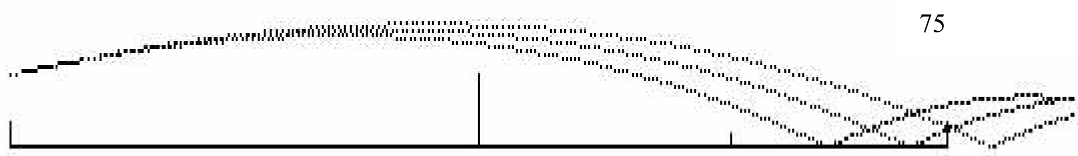


Figure 4

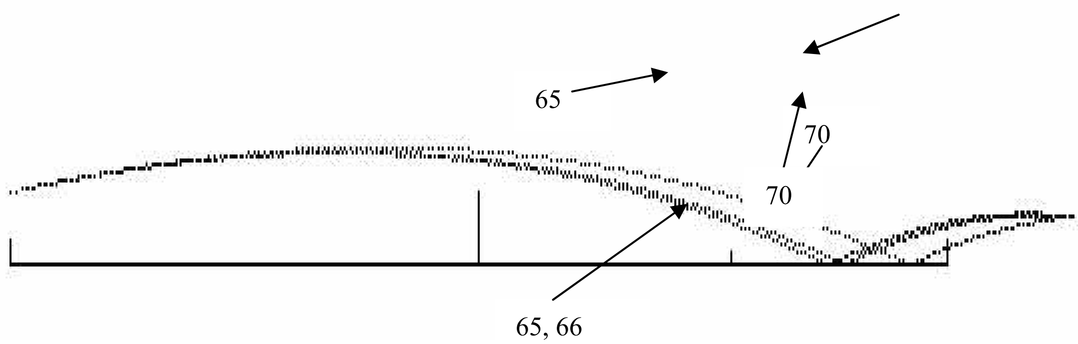


Figure 5