# BALL IMPACT LOCATION ON A TENNIS RACKET HEAD AND ITS INFLUENCE ON BALL SPEED, ARM SHOCK, AND VIBRATION

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**KEY WORDS:** tennis racket, impact location, ball speed, vibration, shock

**INTRODUCTION:** Brody (1988) defined 3 different 'sweet spots' on the strings of a tennis racket. When a ball hits the racket at its point of maximum restitution (COR), the rebound velocity of the ball will be highest. For ball hits at the node of the racket, vibrations are minimal. Ball contacts at the center of percussion (COP) cause minimal shocks to the arm. The definitions of these points are based on the application of the laws of physics to a simple mechanical body - the tennis racket only. In a real game situation, however, tennis rackets are not simple and well-defined mechanical bodies. The player's muscle actions continuously modify the grip forces on the racket handle. Therefore, mechanical coupling of the racket handle with the body is changed with each modification of grip force, resulting in a complex mechanical behavior of the racket-arm system. Using a game-like situation, this study investigated the influence of ball impact location on ball velocity, arm shock, and vibration.

**METHODS:** To determine the location of ball contact and its movement across the tennis racket, thin steel wires were woven around 14 longitudinal and 18 transversal string sections. The steel wires detected the electrical charge of the tennis ball during contact (Hennig & Schnabel 1998). For the measurement of shock and vibration from the racket to the arm, an accelerometer was fastened to the wrist (Proc. styloideus ulnae). Shock and vibration signals were separated by high and low band pass filters. To estimate the magnitude of shock and vibration, both acceleration signals were first rectified and then integrated. Ball velocity was measured by a laser array photocell arrangement above the net. Using the time interval from ball take-off from the racket to the time when the ball crossed the net, the average ball velocity could be calculated. The known distance between player and net was divided by the measured time interval. Each of 19 expert players performed 30 forehand and backhand strokes with a "Kuebler Inertial Light" tennis racket. For this series of measurements the players were instructed to use straight strokes with little spin on the ball. To determine relationships between the variables regression analyses were performed. The figures in this text show x and y axes with the following orientations. The y axis coincides with the longitudinal axis of the racket, with its origin at the center of the racket head. Negative y-values refer to impact locations closer to the racket handle, and with increasing positive values the ball contacts move towards the top of the racket head. The negative x-axis refers to the left side of the racket, as viewed from behind during a serve. For the forehand and backhand strokes, negative x-values identify the upper half of the racket head.

**RESULTS AND DISCUSSION:** Although all subjects belonged to a group of expert players with a similar performance level, the patterns of the ball contacts were quite different between individual players. Figure 1 shows the hitting areas of the ball on the strings for two chosen subjects. These players achieved the highest ball velocities for either the forehand or the backhand strokes. The figures depict the outer boundaries on the strings in which the 30 repetitive tennis ball contacts were recorded. For the chosen expert players all ball contacts were within a small area of approximately 6 cm by 7 cm (dashed area) of the racket head. The dashed areas of the forehand and backhand strokes represent less than 5% and 8% of the total racket head string area. As indicated by the arrow, rolling of the ball on the strings during ball contact moved straight up to the top of the racket (area without pattern). The initial ball contact during the forehand strokes was made slightly left of the racket head center line (upper part of the racket during forehand strokes). For the backhand strokes the ball contacts were located almost symmetrically around the racket head center with a slight shift to the left of the longitudinal axis. Again, rolling of the ball from initial contact to take-off is almost in a straight line towards the top of the racket.

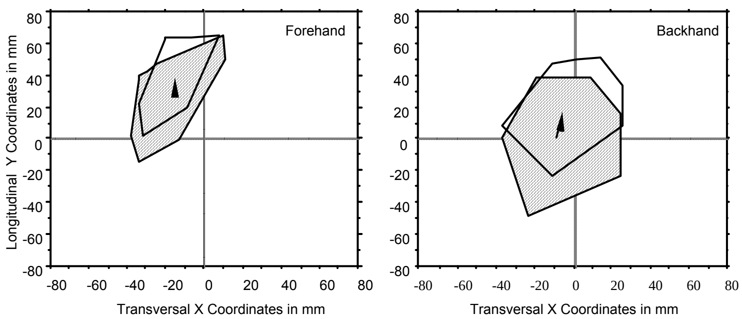


Figure 1: First contact (dashed area) and take-off areas for each 30 repetitive forehand and backhand strokes

Regression analyses were performed to study the relationships between longitudinal impact location, ball velocity, vibration, and shock to the arm. All integrated acceleration signals (shock, vibration) are reported in arbitrary units (AU). Using all trials from all players the shock on the arm increased highly significantly with increasing longitudinal impact locations (forehand r=0.49 / figure 2; backhand r=0.42). Significant 2nd order polynomial relationships were identified between the longitudinal impact location and the vibration load (forehand r=0.65 / figure 2; backhand r=0.65). Table 1 summarizes the numerical values for the COP and the Node of the test racket, as determined by methods suggested by Brody (1988). These values are compared with the results from this study. Minimum shock and vibration locations on the racket head, as identified by this study, are substantially lower than those reported by Brody as COP and Node.

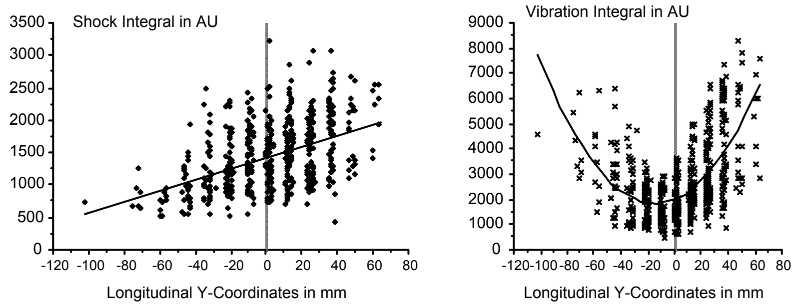


Figure 2: Regression analyses of longitudinal impact location vs. shock and vibration, using 570 forehand strokes from 19 expert players

Table 1: Comparison of COP and Node values with empirically identified points of minimal shock and vibration to the arm in a game like situation

| | Brody, 1988 | Forehand / this study | Backhand / this study |
|---|---|---|---|
| Point of minimum arm shock | 3 mm above string area center (COP) | shock is reduced with lower impact locations | shock is reduced with lower impact locations |
| Point of minimum arm vibration | 23 mm above racket head center (Node) | 18 mm below racket head center | 18 mm below racket head center |

Different anatomical characteristics and individual playing techniques between players increase measurement variability. Therefore, an additional single player regression analysis for forehand strokes was performed. As expected, similar relationships were found. The correlation coefficients increased substantially for the relationships between longitudinal impact location and shock ($r=0.90$, $p<0.01$) as well as vibration ($r=0.90$, $p<0.01$).

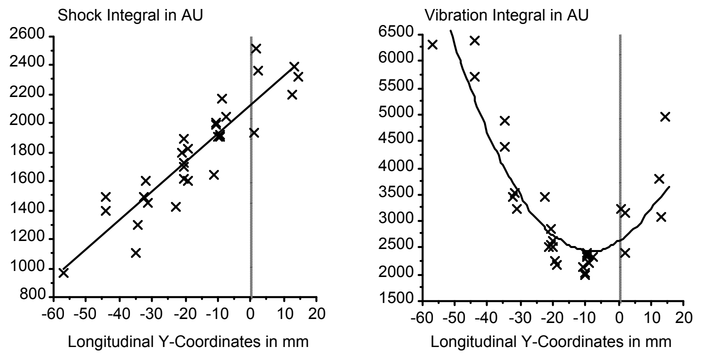


Figure 3: Regression analysis for one player performing 30 forehand strokes

Using the forehand stroke results from all players, low significant 2nd order polynomial relationships were found between ball velocity and the longitudinal ($r=0.18$, $p<0.01$) as well as the transversal ($r=0.23$, $p<0.01$) initial ball contact locations (Figure 4). Brody predicted the point of maximum ball speed would lie below the racket head center. Our data show an opposite trend towards a maximum ball velocity location slightly above the racket head center. Rotation of the racket during the swing increases the velocities for more distally located racket points. Apparently this effect has more influence on ball speed as compared to a lower coefficient of restitution for the racket at higher locations. This phenomenon is known from serves, showing increased ball speeds for impacts above the racket head center. A slight shift of the ball at initial contact to the left of the longitudinal axis seems to increase ball velocity. Most forehand strokes are played with top spin, causing a roll of the ball across the strings. A similar regression analysis for the balls at take-off shows a maximum ball speed along the Y-axis (x=0).

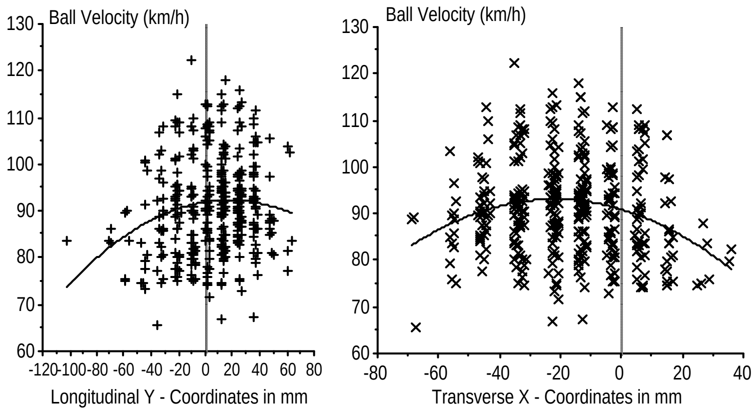


Figure 4: Regression analyses for ball velocity during forehand strokes

**CONCLUSIONS:** Using an instrumented tennis racket 570 forehand and 570 backhand strokes by expert players were analyzed. For ball speed, arm vibration, and arm shock longitudinal and transverse impact locations on the racket head were identified. The results of this study did not confirm the sweet spot racket points hypothesized by Brody (1988) of minimum vibration, minimum shock or maximum ball velocity. Mechanical coupling of the hand with the racket and the contribution of racket rotation during the swing seem to have a major effect on racket characteristics.

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