

ESTABLISHING A METHOD TO DETERMINE IMPACT FORCE IN TENNIS WITH DIFFERENT STRING TENSIONS – A PRELIMINARY STUDY

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The purpose of this study was to establish a method to estimate impact force in the tennis forehand stroke to determine if differences in string tension would affect impact force. This is a preliminary study using only one participant. Estimates were determined using kinematic data and data obtained from strain gauges. Preliminary data on peak resultant impact force estimates were within the range of those reported in the literature. Peak resultant force estimates were larger for higher string tension rackets than lower string tension racquets possibly due to differences in coefficient of restitution. Data estimated from this study, regardless of string tension, may give a better representation of peak resultant impact force as the data were not filtered. Increasing the number of participants or the number of trials will be needed to confirm this preliminary finding.

KEYWORDS: TENNIS, KINEMATICS, IMPACT FORCE, FOREHAND, STRING TENSION

INTRODUCTION: The feedback coaches often give to players during training is to hit the ball hard. Exerting a greater impact force inevitably generates faster ball release speeds, which in turn, could potentially increase the opportunity to score points due to forced errors. Hence, many studies have looked at the kinematics and kinetics of joint movements in tennis (Marshall & Elliot, 2000; Bahamonde, 2000; Fleisig, Nicholls, Elliot & Escamilla, 2003), hoping to understand the technique executed for optimal ball release speeds. To date, only a few studies have looked to quantify impact forces in tennis by looking at force loading on the hand (Knudson, 1991), force loading on the hand using finite elements (Li, Yang, Hwang & Kim, 2009) and using strain gauge on a fixed racket and expressed as a function of ball velocity before impact or by using kinematic data (Wu, Gross, Prentice & Yu, 2001). A factor that could influence ball release speeds and thus impact force may be string tension. String tension usually changes after hitting the ball continuously with the same racket. As such, professional tennis players often have multiple rackets with different string tension at every game. Several studies, performed under laboratory conditions, have investigate how string tension affects rebound speed and accuracy under simulated playing conditions for both males and females (Brody & Knudson, 2000; Cross & Bower, 2001). However, these studies did not investigate impact force *per se*. Since low tension provides greater rebound velocity (Wu, Gross, Prentice & Yu, 2001), it is not known if high string tension rackets generate higher impact force, thus, faster ball release velocities. Knowing the force acting on the ball exerted by a tennis player through a tennis racket with different string tension can be useful information for the player and coach to modify a player's stroke technique. The objective of this preliminary study, therefore, was to establish a method to estimate peak impact forces and to determine if there are differences in impact forces between different string tensions.

METHODS: A single trained semi-professional male tennis player participated in this preliminary study conducted indoors in the Sports Engineering Lab on a makeshift tennis court laid out across the lab with standard netting to mimic actual competition environment. A twelve camera high-speed optical system (Eagle-4 Motion Capture System, Santa Rose, CA) captured the forehand stroke in a three-dimensional (3D) volume space. All cameras, hung strategically on overhead railings, provided a 360° area of foci in the 3D volume space. The frequency for the optical motion capture system was set at 200 Hz.

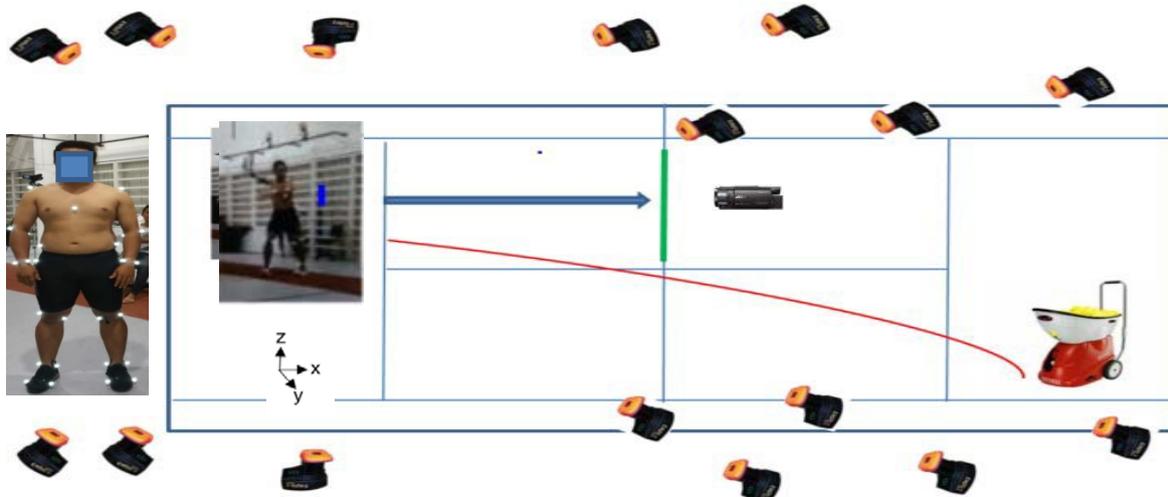


Figure 1: Experimental layout – Camera and Marker Placements

A tennis racket (Wilson Burn 100) was used for this study. Reflective tape was placed at 4 known points around the tennis racket face and a strain gauge was embedded into the body of the racket (Figure 2). Any change in strain measurement (analog signal) was converted to digital signal using an analogue to digital (AD) converter and was synced with the motion capture system. Calibration of the strain gauge was conducted by hanging fixed weights of equal increment on the racket and expressed as a relation of fixed weight mass and strain data (captured on motion capture using a linear regression equation).

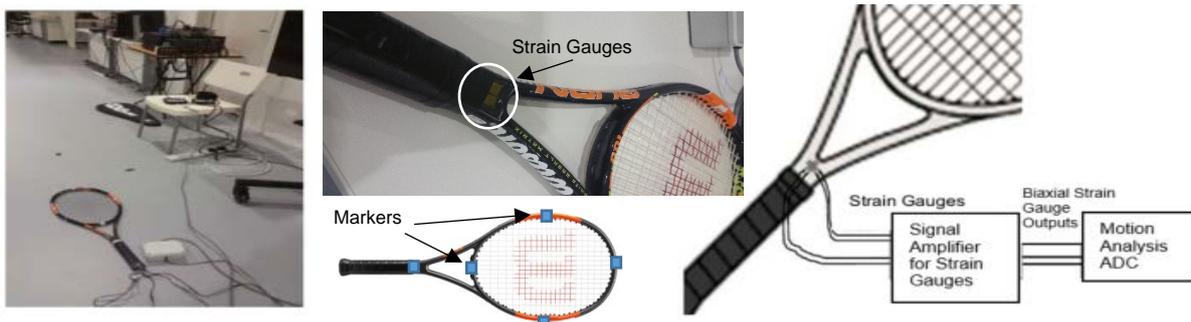
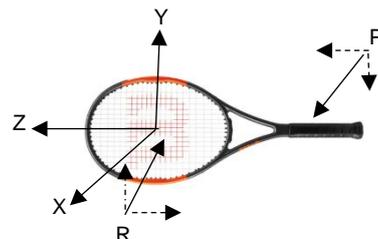


Figure 2: Strain Gauge on Tennis Racket Set-up

The tennis racket was strung twice. First with a string tension of 214 N and second, with a string tension of 258 N. The tennis player performed 25 forehand trials for each string tension on alternate days. For consistency, the ball was fed to the player using a tennis ball launcher. The trial in which the ball hits the target (highlighted as green on the net in Figure 1) was defined as a successful shot. For this preliminary study, only one successful shot was digitized 5 frames before and after impact, from each string tension. The equations (1) and (2) were used to determine the impact force (R_x and R_y) for each string tension is:



$$\Sigma F_x = Max = R_x + P_x \quad (1)$$

$$\Sigma F_y = May = R_y + P_y + Mg \quad (2)$$

where M = mass of racket, a_x and a_y = acceleration, R_x and R_y = impact force, P_x and P_y = force measured from strain gauge and Mg is acceleration due to gravity. Velocity and acceleration of the racket, expressed as x , y and z were determined based on the local coordinate system of the marker position. Position of the centre of mass (COM) of the racket was assumed to be along the z -axis and was determined manually using the distance of two markers (top and bottom) of the racket face and balancing the racket (without the handle) on a bar until balanced. The COM local coordinate system (x , y , and z) was then determined using dot-product based on coordinates and COM acceleration in global coordinate system.

RESULTS: Peak R_x impact force estimates were 277N and 153N and peak R_y impact force estimates were 253N and 76N for 258N and 214 N string tension respectively (Figure 3). Peak resultant impact force estimates were 392N and 264N for 258N and 214N string tension respectively. Ball velocities were larger for 258N string tension. Racket COM acceleration were similar for both string tensions (Figure 4).

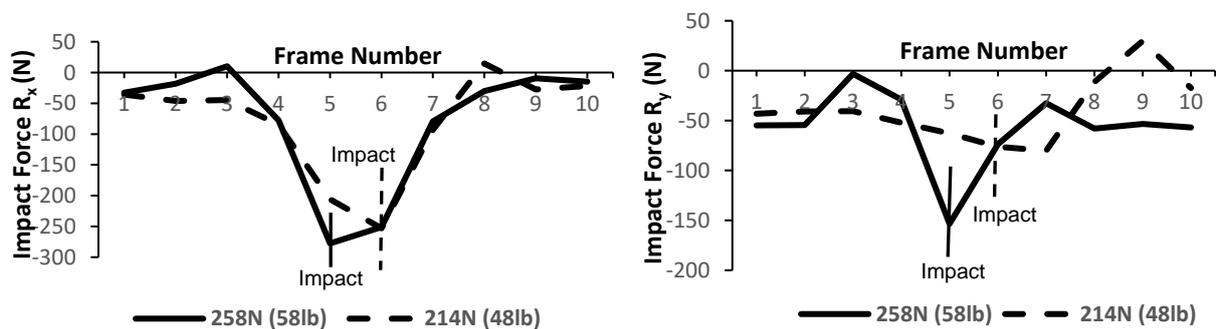


Figure 3: Peak forces normal to the racket surface (R_x) and peak forces parallel to the racket surface and close to vertical direction of the racket movement at the impact (R_y)

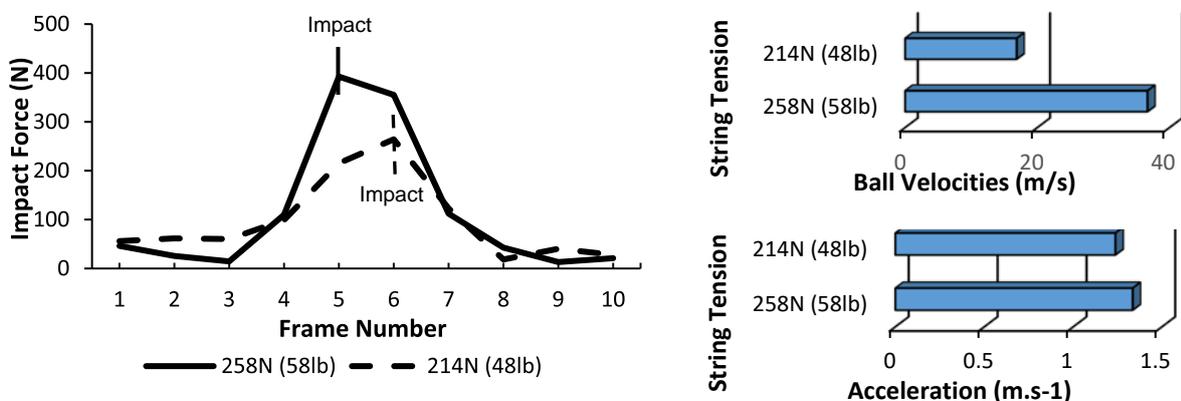


Figure 4: Peak Resultant Impact Force, Ball Velocity and Racket COM Acceleration at impact between Different String Tensions

DISCUSSION: Larger peak R_x impact force estimates (normal to the racket surface) compared to peak R_y impact force estimates (parallel to the racket surface and close to vertical direction of the racket movement at the impact) suggests that R_x forces contribute to ball speeds and the topspin whereas R_y forces may be more related to generating top spin. Difference in magnitude between string tensions may be due to the more control the higher string tension racket gives at impact (Bower & Cross, 2005). The peak impact resultant force estimates were similar to those reported in the literature. For example, using kinematic data only, Yu et al. (2001) reported peak resultant impact forces of 188N and 355N for long backhand strokes and short backhand strokes respectively. Using strain gauges only, Hatze (1976) reported peak resultant impact forces of 377N. Under similar conditions, several studies reported similar peak resultant impact forces. In the current study, we showed that the instant of peak resultant impact force estimates differ between string tensions (Figure 3). The instant of the resultant impact force estimate for the 258N string tension occurred 0.05s earlier than for the 214N

string tension. This suggests that the sampling frequency may be too low. Increasing the sampling rate may increase the number of frames before and after impact which in turn, will affect the timing of the impact force. Studies looking at understanding the impact kinematics and kinetics in soccer kicking have suggested a minimum sampling frequency of 1000 Hz or more (Nunome, Lake, Georgakis & Stergioulas, 2006) where the time duration at impact reported was 10 ms. Despite the sampling frequency of 200 Hz, data estimated from this study may give a representation of peak resultant impact force as the data were not filtered. Should raw data be filtered using conventional Butterworth filtering, a false-peak before impact may be introduced due to over-smoothing (Knudson & Bahamonde, 2001). Hence, preliminary data, measured using kinematic and strain gauge data, suggested that the method used in this study may be suitable to estimate peak resultant impact force. The peak resultant impact force for 258 N string tension was 40% larger than the 214 N string tension possibly due to differences in coefficient of restitution of the different string tensions. Higher string tension rackets have lower coefficient of restitution resulting in slower rebound velocities than lower string tension rackets (Brody, Cross & Lindsey, 2002; Bower & Cross, 2005). With almost similar acceleration at impact (1.23 vs. $1.33 \text{ m}\cdot\text{s}^{-1}$) and larger ball velocity (36.6 vs. $16.8 \text{ m}\cdot\text{s}^{-1}$), it may be that with higher string tension, the string deforms less and the impact duration may be shorter which, in turn, may explain the larger peak resultant impact force for 258 N (higher string tension) string tension than the 214 N (lower string tension) string tension.

CONCLUSION: Unfiltered data estimated from this study may give a representative peak resultant impact force. Larger peak resultant impact force between string tensions may be due to differences in coefficient of restitution as ball velocity was higher while racket COM acceleration was almost identical.

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