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INVESTIGATING THE EFFECT OF TENNIS BALL IMPACT LOCATION

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INTRODUCTION

Tennis is a competitive sport played by millions of people worldwide. The characteristics of the game of tennis produce stress on the musculoskeletal system, especially in the upper extremity. Upper extremity injuries often occur when the arm is highly accelerated, as happens in tennis. These high accelerations require large forces to be applied to the wrist, elbow and shoulder. Upon ball impact, a large amount of force is transferred to the ball from the tennis racket. However, depending on the impact location, large reaction forces can also be produced in the body. These forces must pass through the kinematic chain from the hand to the wrist, elbow and shoulder joints and into the torso. As a result, wrist, elbow and shoulder joint injuries are common. Motion capture systems using retroflective markers are the most common devices used to study the overhead motion in tennis [1]. Movement is measured before and after impact determine what happens at the moment the ball and racket collide, but collision forces are not directly measured.

In this research an instrumented tennis racket and data acquisition system was developed to directly measure the forces and moments caused by ball impact during game play.

METHODS

A custom instrumented tennis racket was designed to measure the forces and torques transferred to the wrist at ball impact. A commercial racket was purchased and a unidirectional surface mounted strain gauge [2] was attached. However, stiffness of the racket was found to be too high for accurate strain measurements, so a modified tennis racket was developed (Figure 1). The regular handle was replaced with a 2.54 cm diameter acetyl rod that allowed the handle to flex at ball impact. The new handle was notched using a Haas VF-1 4 axis mill and was attached to the frame of the racket by two 20 gauge mild steel plates (one on each side) previously cut using a 500W CO_2 Haas laser cutter. The pieces of steel were secured by bolts to rigidly attach the end of the handle to the racket frame. The material used to build the new instrumented tennis racket added additional weight, increasing the mass of the racket from 320 g to 680 g. Unidirectional and triaxial strain gauges were attached to the handle of the racket to measure handle flexion and twist at ball impact.

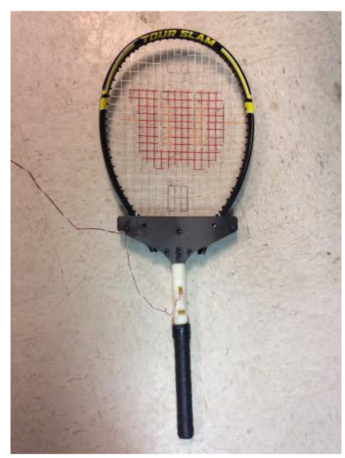


Figure 1: Instrumented tennis racket designed for the experiment.

A Wheatstone Bridge circuit was designed to measure the strain in the gauge attached to the racket handle (Figure 2). The strain signal from the bridge circuit was amplified using the LMC6484 operational amplifier. An additional non-inverting amplifier was added to increase the voltage level to a range that was easily readable by the oscilloscope.

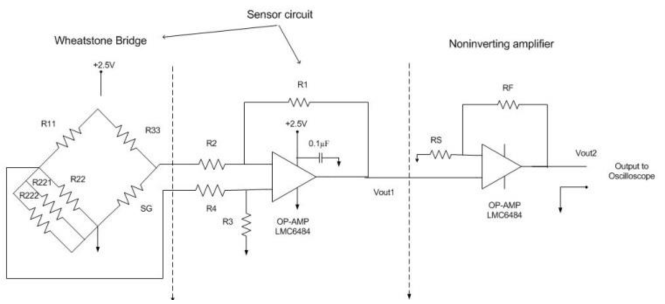


Figure 2: Schematic of the analog circuit used to measure the strain obtained by the strain gauge attached to the racket.

Calibration tests were performed by hanging weights (3 kg, 1.773 kg, 1.182 kg) from the racket at various distances to determine the relationship between externally applied loads and the strain within the racket shaft caused by bending (Figure 3). Trendlines show the linear relationship between the distance and voltage.

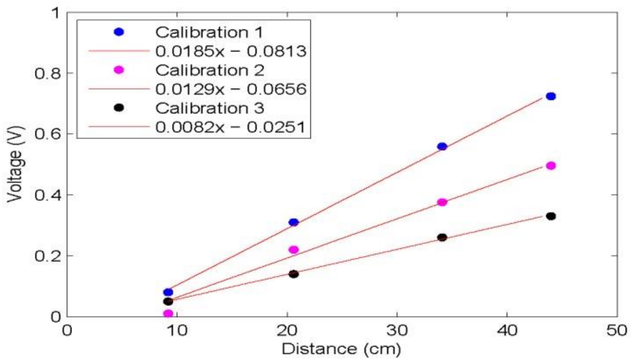
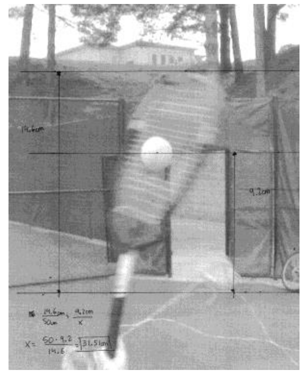


Figure 3: Scaled voltages as a function of distance

Two participants were recruited for the study, one male recreational player and one female athlete tennis player. Participants were provided with the instrumented racket and were asked to stand behind the service line (Figure 4). The test consisted of hitting a total of 20 regular serves. Participants were photographed during the serve using a GoPro Hero3 high speed camera at 120 frames per second.

Figure 4: Participant performing the testing

Each hit was analyzed to identify the frame where the ball made contact with the racket. A screenshot of each impact was generated and ball impact location was calculated (Figure 5). Strain data collected using the oscilloscope was imported into Matlab to produce the graphs corresponding to the strain signal of each impact (Figure 6). Forces and bending moments were calculated for each serve.



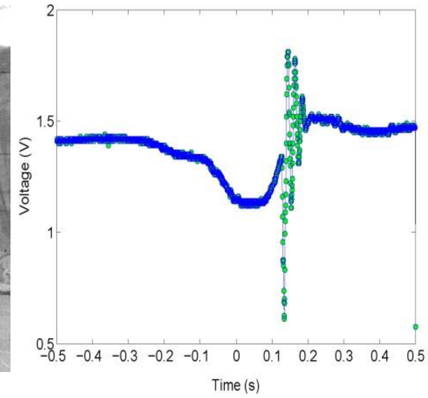


Figure 5: Screenshot of ball impact Figure 6: Strain signal at impact

RESULTS

The instrumented tennis racket system met the design goals. Strain within the racket was captured before, during, and after ball impact. A dip in voltage between -0.3 and 0.1 seconds in figure 8 show the strain caused when the racket is accelerated at the beginning of the serve. Ball impact occurs at 1.2 seconds causing a sharp spike downward followed by rapid oscillations that are quickly damped within 0.1 seconds. The wrist reaction force increase with distance from the handle (Figure 7). Higher forces were observed for the athlete than the recreational player.

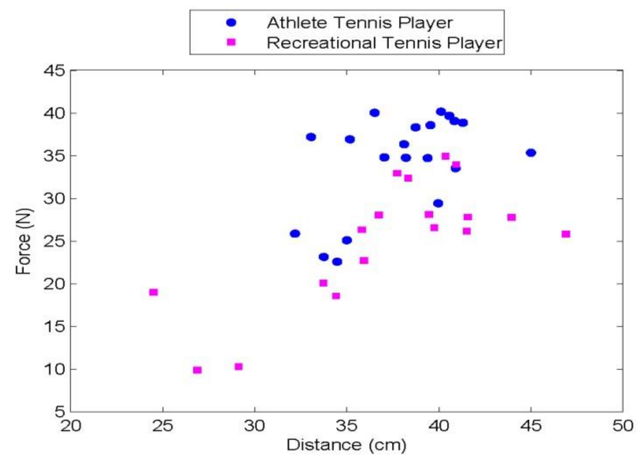


Figure 7: Wrist Reaction Forces at ball impact

DISCUSSION

The system was found to be effective at measuring forces and moments before, during, and after ball impact. Although this research only evaluated wrist reaction forces it could easily be combined with motion capture to develop a richer understanding on impact mechanics. This device or an improved version may also be useful to develop a better understanding of the forces and moments created from different types of movements during tennis play. Ultimately this research may lead to a reduction in injuries or improved performance.

REFERENCES

1. A. Cappozzo et. al, "Position and orientation in space of bones during move-ment: Experimental artifacts," Clinical Biomechanics, vol. 11, no. 2, pp. 90-100, December 1996.
2. N. K. Savage, "Vibration absorption in the tennis grip and the e ects on raquet dynamics", Ph.D. thesis, School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University.