Force Induced on the Brain by Heading Soccer Balls

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The force induced on the brain when an athlete heads a soccer ball is in the spot light in sports medicine today. Soccer players continual use of their heads against a ball and its potential to cause longterm damage is under intense scrutiny [1]. By calculating the force upon impact, analysis and comparison with neurological data, may relate such damage to a professional's career in soccer. From this, it could be determined whether the headgear voluntarily used by some professionals is a benefit in the long term health of their brains. In this experiment, the goal was to simply calculate the force of the ball on a player's brain. By dropping a soccer ball vertically down onto a pig's skull, an accelerometer collected data output as voltage differences. This was then converted to acceleration such that the force could be determined. The accelerations calculated in this experiment ranged up to about 14 g.

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INTRODUCTION

In America today, the National Football League is facing lawsuits from former players claiming football has caused them long term damage to their brains'. One notable case comes from former Philadelphia Eagle fullback Kevin Turner. In 1997, during a routine kickoff, Turner got he significantly hard, leaving him severely concussed for the remainder of the first half of the game [2]. With approval from the trainers on the sidelines, Turner returned to action in the second half, and likewise continued on for an eight year career. Unfortunately for Turner, he is now battling amyotrophic lateral sclerosis, better known as Lou Gehrig's disease, and has been given no more than ten years to live [2]. His lawsuit, claiming the NFL was reckless in handling player head injuries, is one of over 150 similar cases the NFL is preparing to battle against. Kevin Turner isn't a historic, legendary athlete, he rather is an unfortunate human being suffering from the lack of medical knowledge compared to today.

Turner may not be John Elway, but Muhammad Ali is certainly legendary. Ali is not one of 1.5 million Americans suffering from Parkinson's disease [3] which the general population thinks he has. Instead, according to his physician, Ferdi Pacheco, M.D., Ali has Parkinson's Syndrome, which is defined to be caused by physical trauma, which Ali surely endured on his way to three world championships [4].

Even though soccer does not have the attention of the American society compared to others, this is becoming a problem in the Major League Soccer as well as over seas. Players are finally realizing the negative consequences of heading a soccer ball repeatedly over the course of their careers.

To analyze the force on a brain when heading a soccer ball, an experimental process needed to be considered. The design consisted of obtaining a pig's skull from a butcher shop, because pigs are closely analogous to humans. The brain material was created with ballistic gel, and poured into the brain cavity where an accelerometer was placed as well. The accelerometer was chosen because it measures a change in voltage when it is moved, or in this case rattled by the collision of a soccer ball on the skull. This circuit output its voltages into LabVIEW, where the raw data was plotted on three waveform charts relating to the x, y, and z directions independently. This data was exported into IgorPro where the peak voltages where determined and converted to accelerations by way of a proportionality constant. This acceleration was then in turn multiplied by the mass of the "brain", or ballistic gel in this case, which was 0.18 kg so that the force could be determined as the height of the drop point was varied.

THEORY

The goal of the experiment was to measure the force a soccer ball transferred to the brain. Due to complications while calibrating, the force value was not too precise. However the theory remains true. By dropping a soccer ball onto the skull, the accelerometer would shake or rattle within the ballistic gel. This would cause a change in voltage that would be sent from the accelerometer to be displayed on the waveform charts in the LabVIEW program. By exporting the raw data into IgorPro and using the "wavestats" analysis option, the peak voltage change could be recorded for the x, y, and z directions independently. To find the force, the acceleration had to be calculated form the voltage change. This calibration was performed using a mechanical oscillator, a motor spinning wheel. This was inefficient due to warped wood, and was later replaced by simply dropping the accelerometer straight down, falling by the force of gravity.

By doing a linear plot between $a = s\varphi + b$ where a is the acceleration, s the slope, and b the y-intercept, the change in voltage per data point, φ could be determined by this linear proportionality. Without the linearrity, which was determined by $s = 57.65$ (m/s^2)/V and $b = -5.84$ m/s^2 representing the y-intercept, the theory expects

$$\varphi = \sqrt{{\varphi_x}^2 + {\varphi_y}^2 + {\varphi_z}^2}. \quad (1)$$

By using the linearity constants, s and b, with the voltage determined from Eq. 1, the new values were then the acceleration in m/s^2. Then, by multiplying by the mass of the ballistic gel, the force was determined using Newton's second law of motion

$$F = ma. \quad (2)$$

In this way, the two constants from Eq. 2, s and m, provide the necessary dimensions to convert from raw voltages to concrete force values.

The force was also considered in terms of g, rather than Newtons. The g-force is defined to be the force provided to prevent free fall. A human standing on the earth's surface experiences about one g. In 1947, John Stapp, M.D., Ph.D., Colonel, USAF, withstood a g-force of 46.2, suffering only minor injuries during the experiment [6]. His experiment was to study the g-force to better design fighter jet harnesses. To calculate the g-force when heading a soccer ball, the acceleration was simply divided by gravity's acceleration, 9.8 m/s^2.

MATERIALS & METHODS

An accelerometer was used to collect the change in voltage when a soccer ball collided with the skull of a pig. The circuit board for the accelerometer was placed inside the brain cavity and the soccer ball was dropped vertically down so that the repetition of trials could be constant by maintaining the same heights throughout the trials. A LabVIEW program was manipulated to record the motion of the accelerometer in three dimensions, and IgorPro was used to analyze the data.

Circuit

The circuit was built to power the accelerometer and remove some of the noise that accompanies when collecting data. Designed on a breadboard, the circuit was then reassembled, Fig. 1, on a small circuit chip allowing to greatly reduce the size of the circuit. All connections were made tight against the chips face and were then soldered to the back.

The circuit board for the accelerometer was connected to both a breadboard and a NXT Brick that connected to a computer. The breadboard was used to connect the ground and power wires to a power supply. For this accelerometer, it needed to be powered by five volts and also grounded. The NXT Brick was used to connect the

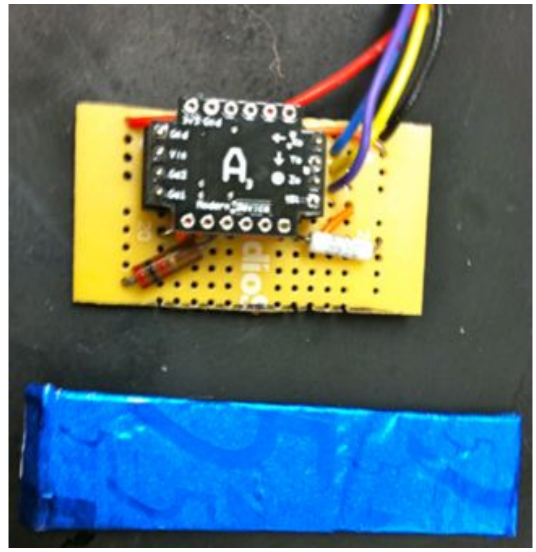

FIG. 1: Completed circuit board shown with a stick of gum for size comparison.

three outputs of the accelerometer correlating to the x, y, and z directions of motion, to the LabVIEW program created on the computer. The accelerometer circuit it-

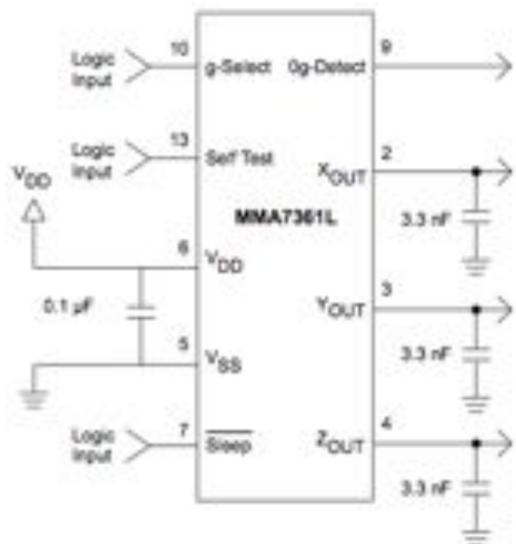

FIG. 2: Electrical schematic for the Modern Device A_3 accelerometer.

self was not overly complicated. Pins 5, 6, and 7 were connected to the NXT Brick to send the output voltages from the accelerometer into the LabVIEW program, shown in Fig. 2. Pin one was connected to ground. The remaining portion of the circuit was used to connect pins 2, 3, and 4 with with +5V from the power supply box. They then connected by running the current through a 2062 kΩ resistor, and then through a second with resistance of 47 kΩ.

Programming

The programming of LabVIEW to accommodate the accelerometer was fairly straight forward by using a previously used VI program developed by Matthew Schmitthenner and Theresa Albon used in an electronics course previously. By adding two additional waveform charts and a while loop, the program produced the information required for my data collection. The most important fact about programming in LabVIEW is to ensure that the computer is in 32 bit mode which can be adjusted on the dashboard.

Materials

For all of the test trials, a watermelon half, carved and filled with ballistic gel, was used. When conducting the final experiment, a pig's skull was used as it is closely analogous with a humans. The head of the pig was boiled in water for seven hours so that the flesh could be easily removed from the bone.

Once carved, the skull air dried before rubber cement was used to cover the passages, such as the eye sockets, nasal and ear passages, and jaw, so that the ballistic gel would not leak out of the brain cavity. Once the rubber cement had dried, the ballistic gel was poured into the brain cavity through the base of the skull where the brain stem would have been. The skull was then refrigerated for five hours so that the ballistic gel could correctly set to the required consistency.

The brain like material used is better known as ballistic gel. This was made by mixing equal parts of Knox gelatin and pectin. The pectin simply increased the stability of the gelatin, as it is a thickening agent used when canning fruits, vegetables, or jams. That dry mixture was added to three parts of boiling water and stirred vigorously until all the dry ingredients were dissolved.

After refrigerating, four small holes were drilled near to the brain stem opening and a chisel was used to complete the final removal of a piece of bone so that the accelerometer circuit had sufficient room to be placed inside the brain cavity. Using a knife, the ballistic gel was given a small slice and a minor amount of gel was removed to produce a pocket for the accelerometer to set neatly within the gel inside the brain cavity for optimal data collection.

Calibration

Because the accelerometer measures a voltage change upon movement, to acquire a force, a proportionality between the two needed to be derived. The initial step was to connect the accelerometer to a mechanical oscillator which would rotate it in a sinusoidal motion. By rotating the accelerometer at two different frequencies, a plot was created in IgorPro which allowed both m and b to be determined. Unfortunately the warping of the oscillator provided inaccurate data. Instead, the accelerometer was simply dropped onto the table and the peak of the voltage was the voltage at 9.8 m/s^2 due to gravity. From this plot, along with zero acceleration at the rest voltage, the proportionality between acceleration and voltage was determined. By multiplying by the mass of the ballistic gel brain, the force induced upon the brain could be determined.

Procedure

Once the skull was properly prepared by carving off the flesh, adding the ballistic gel, and removing excess bone, the gel was sliced to allow room for the accelerometer to be inserted into the brain cavity. The skull was then placed on the floor and a small plastic bag was used to cover the accelerometer from the gel. Once the skull, breadboard and NXT brick were in place, the LabVIEW program ran to collect the data. To get a measurement of soccer balls force on the brain, a soccer ball was dropped vertically down onto the skull. Three trials were conducted per height varying from 0.5 m to 3 m. The largest difficulty in collecting consistent data was the variance at which the soccer ball could potentially collide with the skull. The placement of the the skull on the floor was reset to a control spot, Fig. 3, after each trial to maintain consistency. Also, the accelerometer was checked after each trial to ensure it remained in the correct place. To maintain consistent measurements of the hight of the dropping point, five meter sticks were attached to one another stretching from the floor to the ceiling. By dropping the ball straight down, each of the trials per height theoretically should accelerate at 9.8 m/s^2, with gravity acting as the only force on the ball. The negative of dropping the soccer ball in this manner is the accuracy of the height is a simple eyeball test which allows for what

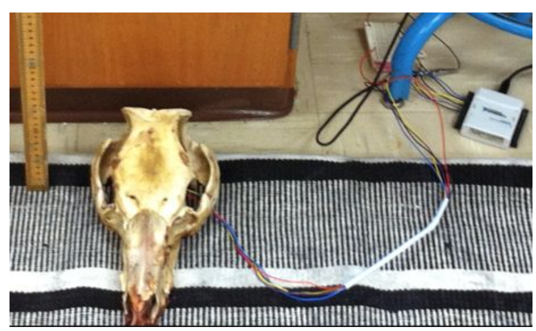

FIG. 3: Pig's skull placed on the floor beside a meter stick used to maintain accurate drop heights.

could be potentially significant error.

DATA ANALYSIS

Even though time hindered expansive data collection, some interesting results were analyzed. By analyzing the voltage as the sum of the root of the squares, Eq. 1, I was able to determine the linearity constants $s = 57.65\ (\mathrm{m/s^2})/\mathrm{V}$ and $b = -5.84\mathrm{m/s^2}$. Looking at Eq. 2, the relationship between voltage and force requires this constant, along with the mass of the"brain," determined from weighing the ballistic gel.

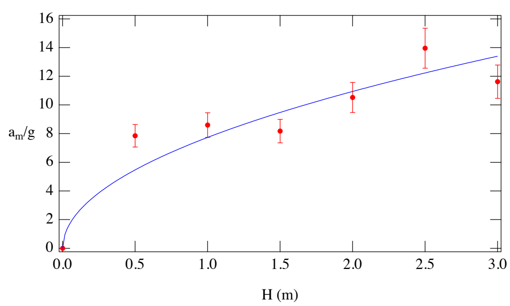

FIG. 4: Maximum brain acceleration a_m as a fraction of g versus the drop height, H, in meters. The Blue curve assumes the brains acceleration is proportional to the impact speed.

As shown in Fig. 4, the accelereation was shown in relation to the g-force. The g-force at the maximum reached 14 g. This is an incredible amount of force when knowing a high performance, top-fuel dragster only reaches roughly 5.4 g [5]. Even though humans are capable of withstanding large amounts of g-force, it can only be for short periods of time. The larger the g-force, the less time a human can tolerate it.

CONCLUSIONS

Based on the data, no conclusion may be made regarding brain damage, long term affects, or whether head gear would better protect players. However, with the data collected and my ability to reproduce the data, determine proportionalities, and obtain realistic values for the force, it is able to be said that a human brain withstands a significant amount of motion from the force created when heading a soccer ball. This force could potentially be damaging soccer players brains which may lead to long term problems.

FURTHER RESEARCH

Unfortunately, due to a combination of time and materials, my data collection was severely rushed. With ample time, this process could be much more accurate. The calibration was the largest error to overcome, and with more time, a much better calibration could be obtained. Also, I was unable to reach the heights necessary to really see any significant damaged to induced on the brain. This again was due to such a short time period to collect data along with my inability to create a program that would be able to be loaded completely onto an NXT Brick and then attached after data collection was complete. This ability to obtain a higher range of heights would greatly increase the relevance of the data set.

I would very much like to continue this research as a senior thesis. My goals would be to recreate the procedure used in this experiment, however; using a better calibration technique, a much broader range of heights, variance in the amount of air pressure within the soccer ball, and even dropping soccer balls that have been soaked in water to see how those changes affect the brain [7]. I think that research is not only a hot topic in sports around the world, but I am confident that I will be able to draw clear cut results that will either support the use of headgear in soccer or oppose it.

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