Accelerations of the Head due to Soccer Ball Heading

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Abstract and Specific Aims

Project Summary:

Athletes in general are at a greater risk than the wider population for head trauma, or physical injury to the head. Investigations into the cause and severity of head injuries during sports play are relevant to the safety of athletes. Currently, the biomechanics of head trauma are not well understood. There is conflicting research concerning which impacts are likely to cause severe head trauma with symptoms of concussion (e.g. disorientation, dizziness, memory loss), what physical mechanisms are responsible for head trauma, and what can be done to prevent head trauma. Of particular concern is the potential lasting harm an impact to the head can have on children, whose bodies are still developing. A study is proposed to develop and evaluate tools to quantitatively measure the accelerations of the head during soccer ball heading. Head accelerations will be measured using a wireless mouthguard with attached accelerometers. Additional information about the impact, including pre- and post-impact velocities and the impulse delivered by the ball to the head, will be accomplished through analysis of high speed digital recordings of each heading event. Certain physical attributes of the player will also be recorded to determine whether a correlation with head accelerations is suggested. The muscularity of the neck will be assessed by measuring the circumference of the player's neck and conducting a bio-electrical impedance analysis on each player to determine the player's muscle-to-fat ratio.

Project Goals:

The primary goal of the project is to have a successfully operating wireless mouthpiece with which accelerations of the head can be accurately measured. A secondary goal is to collect information on the neck musculature and body composition of each player to determine whether a suggested correlation is present that would warrant further study. This project is intended to be ongoing, and is itself a continuation of a previous project. A mouthpiece instrumented with a single accelerometer was developed by Paris et al, 2010, and a wireless mouthpiece instrumented with three 3-axis accelerometers was developed by Kara et al, 2011. A similar mouthpiece will be designed and constructed for this study by employing modifications suggested by the

performance of the previous incarnation of the mouthpiece. For example, the 3-axis accelerometers used to instrument the previous mouthpiece suffered from performance issues, and will be replaced by more robust 1- axis or 2-axis accelerometers. Another adaptation will be the inclusion of information regarding the physicality of the player. Successful use of a bio-electronic impedance analyzer will result in a body composition for the player participating in heading sessions. Finally, integration of the head acceleration during the impact will be explored to quantify accelerations over the entire impact rather than just looking at the peak.

Introduction:

With the growing popularity of sports, there are increasing concerns over the effects of repeated head trauma, particularly at the youth and college levels. The biomechanics of head trauma is presently the study of much active research. There is currently not a consensus on the physical mechanisms that cause head trauma, preventative measures which may be taken to protect athletes, or even the medical definition of a concussion. The National Institute of Health defines head injury as occupying a range from a bump on the head to the fracturing of the skull (NIH, 2011). These injuries are not necessarily visible and could include bruising of the brain. "Some head injuries result in prolonged or nonreversible brain damage (NIH, 2011)." A study done by the University of North Carolina reports that professional athletes who had suffered repeated concussions have reported the onset of dementia-related symptoms including problems with memory, concentration, speech impediments, and headaches (Guskiewicz, et al, 2005). Soccer is the only sport in which the head is deliberately used to strike the ball, and the safety of soccer ball heading is still a matter of debate, particularly at the youth and college levels (Leightly, 2011).

Previous studies have investigated the relationship between heading technique and head accelerations, as well as the physical properties of the balls themselves (Shewchenko, et al, 2005). There has also been investigation into the effects of and timing of neck muscles when a player is heading a soccer ball. It was found that different neck muscles engage at different time depending on the placement of the soccer ball (Shewchenko, et al, 2005). While studies of neck musculature and head acceleration have been conducted, studies have not examined the total muscularity of the player with regard to head acceleration. Because core muscles form the foundation of overall strength (McGill, 2003), it is hypothesized that overall muscularity of a player is factor in the acceleration of the player's head when heading a soccer ball. Although the sample size for the proposed research will be too small to draw definitive conclusions, any suggested correlations will suggest avenues for further study.

Research Design:

Adult soccer players will make up the sample population. A single player will be recruited who is in good physical condition, and will be aged 18-35. Prior to the player's involvement in heading soccer balls, he or she will undergo a body composition analysis using a bio-electrical impedance analyzer, the Ormon Body Composition Monitor or similar device. Once information about the physical structure of the player is gathered, the player will be fitted for a custom acrylic instrumented mouthpiece. The mouthpiece will be custom made and fitted by Four Corners Dental, LLC, or similar dental clinic, using a mold of the player's teeth to ensure proper fit. The design and appearance of the mouthpiece will be similar to that shown in Fig. 1. The mouthpiece will be instrumented with multiple accelerometers and a wireless data transmitter. A laptop computer connected to a wireless data receiver will be used to record data from the mouthpiece.

Figure 1: Photograph of a wax mold for a mouthguard similar to those that will be used in the proposed research. One 3-axis accelerometer is shown placed at (a), and the mounting screws for the other two accelerometers are shown placed at (b) and (c). In the proposed research 2-axis accelerometers will be used.

After the body analysis and mouthpiece fitting is completed, the player will begin soccer ball heading sessions. Soccer balls will be launched at the player using a soccer ball launcher (Sports Soccer Machine M1800, Jugs Sports Equipment) at speeds up to approximately 40 mph, and falling within speeds that have been observed in regulation play. Accelerations of the head will be recorded on a laptop via the instrumented mouthguard in the player's mouth. In addition, each heading event will be recorded using a high speed (HS) camera (HotShot 512 INT, NAC Image Technology, Inc.). The HS camera is capable of recording 2000 frames per second (fps) at its full resolution of 512x512 pixels. The HS video will ensure that the relative positions of the ball and head, as well as the geometric deformation of the ball, can be monitored with a high degree of accuracy during the course of each heading event. There will be four sessions, with the first session being devoted to familiarizing the player with the experimental procedure

and calibrating the equipment. Subsequent sessions will involve the player heading balls at four different speeds and heading at least four balls at each speed.

Data from the mouthguard will be analyzed using Microsoft Excel. Previous research has demonstrated that peak acceleration is not a reliable indicator of concussion risk, because it only considers a single moment of the impact (Gadd, 1966). In order to correlate accelerations of the head resulting from head impact, previous researchers have explored different schemes for integrating head accelerations over time with different weight factors. One of the goals of the current research is to develop a method to numerically integrate the accelerometer data from the mouthpiece over the total time of the impact.

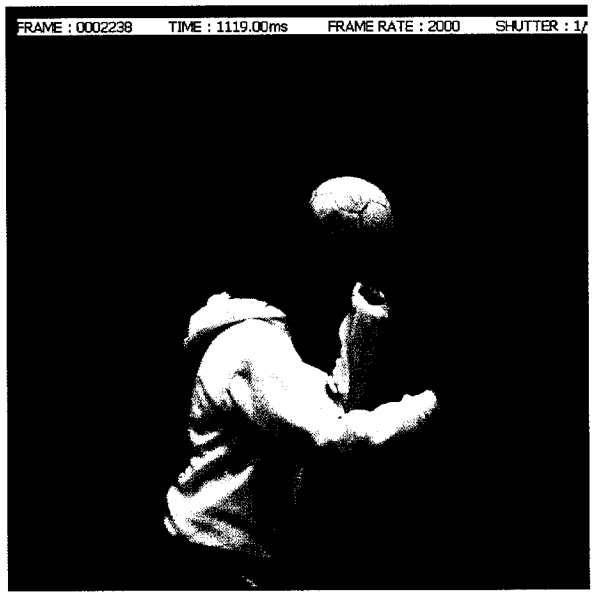

Figure 2: A single frame for a high-speed video of a heading event with a female volunteer, showing the maximum geometric deformation of the ball.

Data from the HS camera will be analyzed using the Image Processing toolbox available with MATLAB. Frame-by-frame analysis of the HS video will be performed to determine the pre and post impact speeds of the soccer ball, as well as the changing size of the contact patch between the ball and head as a function of time during the impact (see Fig. 2). This data will be multiplied by the ball pressure to determine force acting on the head from the ball as a function of time according to

$$F = p\pi d^2/4 \qquad (1)$$

where p is the pressure in the ball and d is the diameter of the contact patch with the player's head measured in the video. The force curve will be integrated over the course of the entire impact to determine the total impulse delivered by the ball to the head.

Anticipated Results:

The participant's physical attributes (height, weight, sex, muscle mass, bone mass, and body mass index) will be measured prior to soccer ball heading sessions using the Ormon Body Composition Monitor. The velocity, pressure, diameter and mass of the ball will also be recorded prior to each session. Heading sessions will be recorded at 2000 frames/sec using a HS camera, and used to compute the pre- and post-impact velocities and total impulse delivered to the head by the ball using MATLAB. It is anticipated, based on the results of previous studies, that the relationships between peak head acceleration and pre-impact velocity will be linear (Paris et al, 2010). It is further anticipated that the relationships between peak ball-to-head force and pre-impact velocity, as well as total impulse and pre-impact velocity, will also be linear (Paris et al, 2008; Kara et al, 2011). In addition to examining relationships between pre-impact velocity and peak accelerations, it is anticipated that numerical integration of the head accelerations over the course of the impact will yield additional information.

It is anticipated that the overall muscularity of the player will contribute to the acceleration the player's head undergoes. The data may suggest that players with a strong core group of muscles are better able to resist rotational accelerations of the head during a soccer ball heading. The population sample proposed for the current research will of course be too small to draw definitive conclusions, but if correlations are suggested, they will guide future projects which may deal with larger populations of players.

In additional to submitting a report to the Undergraduate Research Symposium, the results of this study will be written up for submission to the Journal of Biomechanical Engineering.

Project Budget:

Four Corners Dental – Lab work$425	$425
Mouthguard construction, $500	$500
Analog Device 3-axis accelerometers, 3@ $250.34/ea	$750
Solder reflow hot plate	$300
Custom PCB, $100	$100
Dow Corning 3140 Silicon, 2 @ $40/ea	$80
Li-poly batteries, $12	$12
Texas Instrument wireless transmitter, $50	$50
Volunteer compensation, $150	$150
Ormon Body Composition Monitor	$72
School of Engineering matching funds	<$439>
Total	$2,000

Budget Justification

Constructing the mouthpiece to be worn by the player will require not only the components to assemble them, but a dentist to fit the mouthpieces to the participant's mouth. Four Corners Dental, or similar clinic, will take imprints of the player's mouth, and construction of the mouthpiece itself will be contracted by Four Corners Dental, or similar clinic. The accelerometers will be attached to the mouthguard. Currently, the budget includes the 3-axis accelerometers used for previous incarnations, because we have not yet identified which 1-axis or 2-axis accelerometer chips we wish to use. It is anticipated that the accelerometer chips will be less expensive because the 3-axis accelerometer chips are very new technology, so $250 per chip is a very conservative estimate. If the chosen accelerometer chips do end up being equally expensive, matching funds from the School of Engineering will accommodate the slight increase in funds over $2000. The silicon, the Li-poly batteries, and the wireless transmitter are all required in the construction of the mouthguard and transmission of data from the mouthguard to a computer. A solder reflow hot plate and custom printed circuit board (PCB) will help cut down production time and effort due to soldering. The player will be compensated as per IRB guidelines. The body composition monitor will help identify the muscularity of the player which will be used in the data analysis.

Project References

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Project Timeline

December 2011-January 2012

- Submit application for review
- Find and contract soccer players
- Order Ormon Body Composition Monitor
- Coordinate with dentist Jamison Spencer to custom fit mouthguards

January – February 2012

- Send participant for mouth guard fitting
- Debug mouth guard and send participant for second fitting if necessary
- Acquire data

March-April 2012

- Analyze data
- Write final report
- Undergraduate Research Symposium