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Investigation of Asymmetric Impacts on Protective Headgear

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INVESTIGATION OF ASYMMETRIC IMPACTS ON PROTECTIVE HEAD GEAR

A Capstone Experience/Thesis Project

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Honors College Graduate Distinction at Western Kentucky University

By

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ABSTRACT

This project explores helmet-to-helmet impacts and their detriments with a unique perspective. The propagation of dangerous waves into the brain can result in a concussion. Considering 60% of NFL players have had at least one concussion (Epstein 2011), it is imperative to understand the materials that construct helmets and observe how these materials behave in regards to impact location while recording wave propagations from the impacts. This study interrogates the effect of asymmetric impacts on gridiron football helmets using the Large Chamber Scanning Electron Microscope (LC-SEM). Utilizing two standard issued football helmets made of polycarbonates, a hard plastic, vibrations from a controlled impacted recorded by accelerometers placed along the shell of the helmet measured waves of ±4g force. The frontal impact recordings depicted higher single peaks, while side impacts revealed vibrational relatively lower peaks. To investigate the response of the helmet material to collisions, helmet impacts were carried out in air using a specific pendulum apparatus (to simulate the collisions) and 179 N of force. It was subsequently studied in the LC-SEM and the images depicted clear damage to the helmet shell. Ultimately, this project seeks to provide aid in the endeavor of concussion prevention headgear.

Keywords: Helmet, Collision, Concussion, Waves, Accelerometer, Microscope

Dedicated to
Jace Lux

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FIELDS OF STUDY

Major Field: Health Sciences

Minor Field: Biology

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INTRODUCTION

The game of football stems as far back as 2500 BCE, and expanded from areas of Asia (Britannica Encyclopedia). Eventually it reached America in the 1880's, but didn't gain popularity until after World War II when John Thorpe developed the National Football league. The evolution of the football helmet follows the establishment of the game into American pop culture. As it grew in popularity, it also became exponentially more violent. Helmets started as simple leather padding to prevent injury, but in actuality gave little protection. It wasn't until 1940 when the more modern plastic football helmets with a chin strap facemask were developed and patented by the John T. Riddell Company, which has reduced deaths by nearly 70 % (Levy 2004). These football helmets are the center of the study and focus on how well they actually protect athletes from concussion. Dr. Lawrence M. Lewis and associates note in their study "Do Football Helmets Reduce Acceleration of Impact in Blunt Head Injuries?" that helmets do in fact reduce the force peak of an impact (2008). However, experts debate the extent of protection.

For decades, multiple efforts developing better helmets for players have consumed the sport industry, especially, concerning concussion prevention. Riddell, major contributor of protective gear in the NFL (Riddell 2015), has advertised their attempts to create head that prevents concussions. In fact, in 2002 the University of Pittsburg Medical revealed that the company developed a helmet that would reduce concussions by 31% (Iverson 2006). However, this conclusion proved unsupported by the data and Riddell had to retract their statement. Even with the ban of helmet-to-helmet collisions of defenseless players, just a couple of years ago New Orleans Saints became under scrutiny for a bounty system for injuring other players (Coffey, 2012).

As a result, the National Football League (NFL) has received attention recently for not providing the necessary protective gear for its athletes. Studies suggest while a slight decrease in concussions does occur, in professional leagues, concussions are still a significant issue (Lewis 2008). While, concussion research has included a variety of techniques to decrease injury, our current project provides a unique perspective to assist in identifying ways to mitigate concussions due to multiple collisions. This project seeks to interrogate the effect of asymmetric impacts on gridiron football helmets using simulated impacts in combination with the imaging capabilities of the Large Chamber Scanning Electron Microscope (LC-SEM). Current helmet technology produces protective headgear that can withstand about 548 pounds of force (Riddell 2015). As new materials for these protective systems are developed, the ability to predict and test in "near real world" situations are key to maximum protection of the athlete.

During a helmet-to-helmet collision, vibrations from the impact propagate on the surface of the protective headgear in a complex fashion. The materials that comprise the headgear must maintain their integrity after multiple acute stress conditions. Current headgear architectures still allow for the transmission of dangerous waves into the brain resulting in the damage and destruction of thread-like fibers in the arachnoid, a protective layer around the brain that is meant to keep it secure. When the fibers are broken, the brain shifts. The effect is seen as a concussion; when the head experiences a sudden jolt and soft tissue in the brain moves in reaction to the sudden force (Web-Md 2013). This sudden force alters brain cells and results in the release of all neurotransmitters in an unhealthy cascade, flooding the brain with chemicals and dulling receptors linked to learning and memory.

Immediately after injury, an individual may experience confusion and disorientation, along with nausea and blurred vision. While many symptoms appear instantly, others may not surface for weeks. Delayed symptoms tend to be more drastic, including changes in behavior, such as aggressive tendencies, paranoia and suicidal tendencies (Web-Md 2013). On the college level 34% of players have had at least one concussion, and 20% have had multiple. By the time a player reaches the NFL more than 60% of the players will have at least one concussion, and 45.7% will endure multiple concussions (Ebstein 2011). When an individual experiences multiple concussions it may ultimately result in degenerative brain diseases, such as Parkinson's Disease, Lewy Body dementia, or Alzheimer's Disease (Web-MD 2013). A fundamental understanding of the materials that construct the helmet, how these materials behave over time, and their ability to mitigate transmission of waves into the brain is obligatory. A strategy rooted in science can then be developed to reduce injuries and aide in developing novel materials and helmet architectures from these helmet-to-helmet collisions.

In 2013, the Baltimore Ravens in the Super Bowl used the new Xenith helmet manufactured in Lowell, MA. This helmet varies from the more common Riddell helmet because it advertises an inflatable padding and thermoplastic material, rather than a standard polycarbonate plastic, which the company suggests can adapt with dependency on the collision (Xenith 2013). With new innovated models developing it is imperative to look at more unique perspectives of analyzing helmets. The LC-SEM provides real-space imaging to track minor changes in the surface morphology on the helmet that may result in diminished protective capacity. This initial study has the potential to contribute to the advancement of sports medicine in its endeavors to decrease the occurrences of concussions inflicted on football players and may provide a blueprint for other headgear technology. Currently, polycarbonate plastics are the main materials being used by the companies providing the NFL with protective headgear. In an effort to provide increased safety for its players, the NFL has called for a well-rounded comprehensive investigation into the role these and other novel materials play. Since shock waves on impact cause the concussion, this project may be used for future studies to evaluate the best method for wave suppression in the development of enhanced helmet architectures.

CHAPTER 2

METHODS

To investigate the response of each helmet material to a collision, helmet impacts were carried out in air using a specific pendulum apparatus (to simulate the real-life collisions). Before and after collision changes were observed in the LC-SEM; however the collision waves from the pendulum apparatus was not measured with the accelerometers. The experimental setup, however, did not allow for a precise impact location. Real-space imaging of the surface of the polycarbonate helmet at the impact site(s) were carried out nondestructively using the LC-SEM using backscattered electrons (BSE). Since the helmets are non-conductive the LC-SEM operated in variable pressure mode was needed to carry out the experiment. The benefit in using this mode is not requiring to sputter-coat the surface of the helmet in a conducting medium to facilitate imaging of the surface.

Initially, the helmet was imaged prior to impact using the LC-SEM to evaluate the morphology of the surface prior to being subjected to impact. To study the change in surface morphology, the previously scanned helmet was secured to a platform. A second helmet of the same model and size was hung from the pendulum apparatus and filled with 40 lb (18.2 kg) of lead masses in order to mimic the force of a real-life collision. Lifting the weighted helmet about a meter and half from the ground provided the necessary assistance of gravitational force to create 179N to impact the helmet. These calculations of force were identified as such:

Force of Impact= Force of Gravity= mg= (18.2 kg)(9.81m/s^2)= 179 N

Where *m* is the mass of the weighted helmet and *g* is the acceleration of gravity. This process was repeated several times along the same impact location. Changes in surface morphology were observed by scanning the helmet a second time using the same backscatter electrons in variable pressure mode conditions. The image was used to identify grooves, scratches, and dents in the helmet.

The same standard issued Riddell football helmets made of polycarbonates was used to measure vibrations from a controlled impact with accelerometers placed along the exterior of the helmet approximately 2.54 cm apart Figure 1.

Figure 1. Image of helmets depicting transverse and longitudinal graphing of the accelerometers placement.

Accelerometers monitoring the vibrations from a controlled impact were used to study the evolution of the wave as it traveled on the surface of the helmet. The accelerometers from Digilent Inc., were model number PmodACL and are 3-axis accelerometer modules powered by an Analog Devices ADXL345 accelerometer chip.

For our application the I2C controller mode was used for communication. Since the devices only supported two separate I2C addresses, the addresses were set via software using the digital outputs of the myRIO to communicate with more than one accelerometer. The accelerometer that was to be queried was set to one of the available addresses and the other accelerometers were set to the alternate address. This process continued rapidly cycling through each accelerometer. Accelerometers were placed in longitudinal and transverse directions relative to the front of the helmet. The positions chosen as the frontal and side impacts are the most common areas of impact, and are therefore ideal for this research (Pellman 2003).

Data collection was carried out using custom designed LabView software, which measures acceleration in terms of g (9.81 m/s^2) along a time line of 3-10 seconds for each impact. The accelerometers depicted in Figure 2a-b recorded the frequency of wave form data in versus time, which was determined by the sample rate (1/sample rate). Recorded vibrations were used to observe the differences of frontal versus side impacts on headgear by the measuring the manner in which the impact waves propagated about the helmet.

Figure 2 a. Accelerometers used for recording waves

Figure 2 b. example of frontal placement along the shell

The MyRio device interfaced to the computer and the three accelerometers. The LabView 2014 32-bit program was used for this study is depicted in Figure 3. Three second intervals were selected for the duration of 3 seconds, and the resolution was set to ± 4g to measure the smaller impact and the waves that propagated along the surface of the helmet. The run arrow was pressed and the waves were measured using accelerometers. While they recorded waves in the x, y, and z coordinates, only z was used for analysis because these waves enters the cranial space. In other words, these waves interact with the brain and fibers securing it while x and y are tangent to the helmet. After the duration concluded a the data was saved onto a thumb drive connected to the MyRIO under a file labeled "acceleration data."

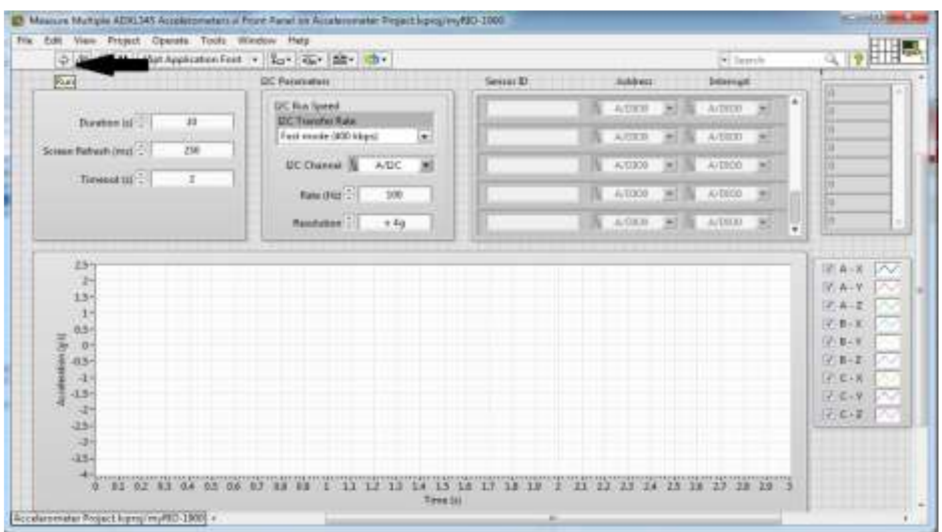

Figure 3. MyRio screen with arrow pointing to "Run", which was used to record the data depicting 10 second duration with ±4g resolution

To develop an understanding of the manner in which the wave propagates along the surface of the helmet, a method was developed using smaller impact forces. The advantage of this was to proceed in a more controlled way and to generate similar impact waves every time. To accomplish this, a small hammer was used on two selected locations on the surface of the helmet. The impact locations were selected based on the most common areas of impact recorded amongst football in-game collisions (Pellman 2003). They were isolated and kept constant by securing a small blunt tip to the helmet as demonstrated by Figure 4.

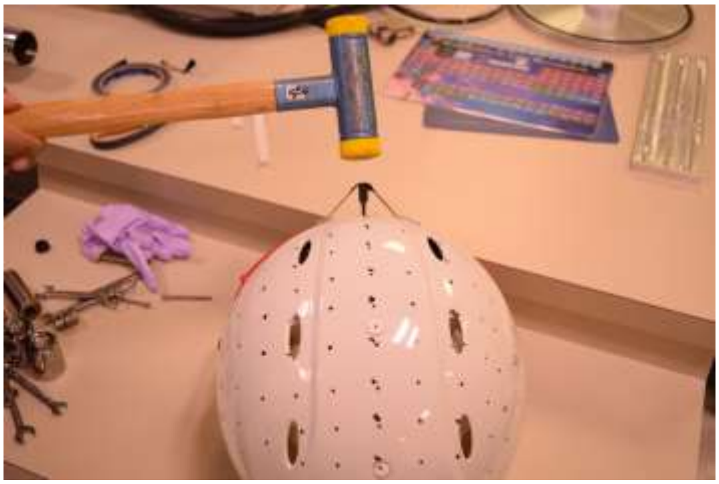

Figure 4. Small blunt flat tipped screw head and hammer used to create specific impact sight for testing.

The waves were measured using three accelerometers (A, B, C). One accelerometer (A) was located directly adjacent to the impact sight to record initial wave that would be produced by the impact. The second accelerometer (B) was placed to the right of the impact sight and the last one (C) was placed to the left. Each recorded various locations in a systematic way along the indicated points, as displayed in the image in Figure 3 above. A sample of accelerometer data of the frontal impact point is displayed in Figure 5 in terms of g (9.81 m/s^2) versus time. Multiple impacts were carried out along lines of the shell and the subsequent raw data was averaged to reduce error from unequal impacts using equation 1 and combined on one graph as displayed in Figure 6.

Average Peaks = ∑initial impact peaks/ # of impacts **Equation 1**

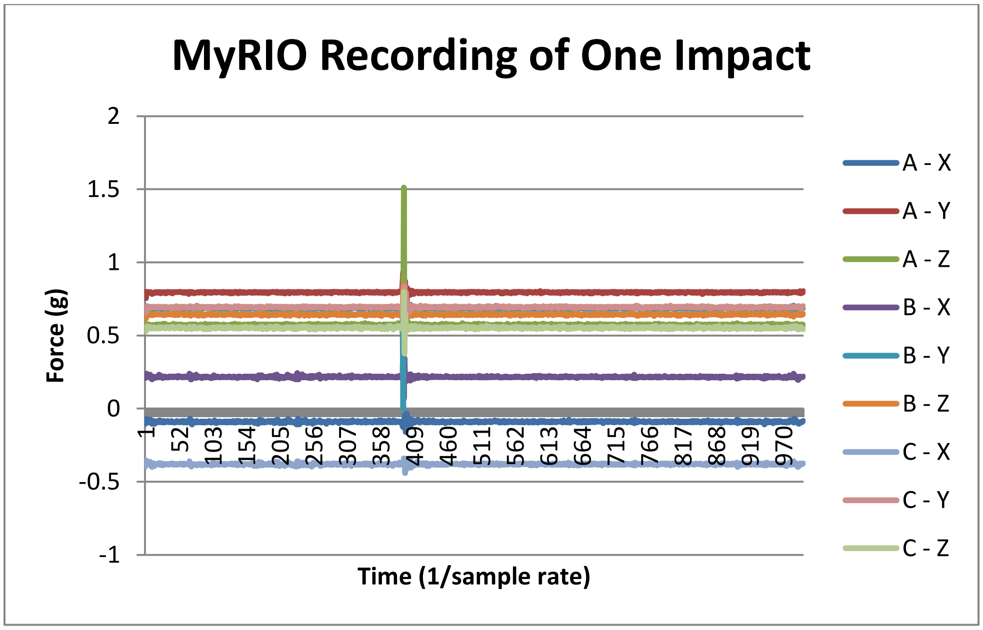

Figure 5. Single impact recording from the MyRIO. It recorded waves in the x, y, and z coordinates from accelerometers A,B, and C.

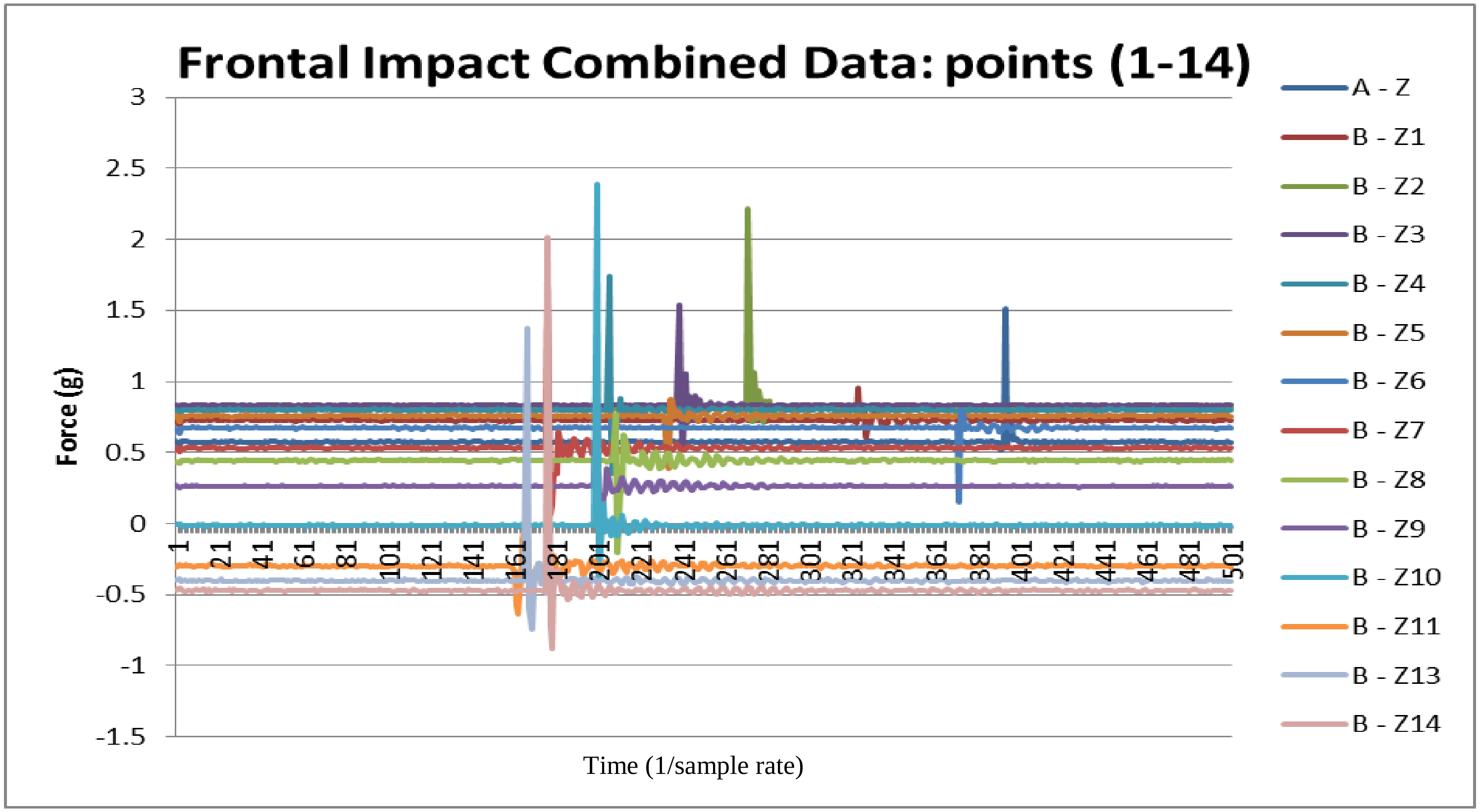

Figure 6. Graphed peaks of Raw Combined Data along longitudinal line A in terms of g/s. A-Z is the initial impact point. Points B-Z (1-14) are the tested points along the longitudinal line of row A on the helmet.

Clearly from figure 6 the data is difficult to interrupt in terms of time. Therefore, the data was set to relative distance from the impact point to illustrate change in amplitude as the wave propagated along the shell. The impacts were tested five times and the data were normalized to equation 2 to remove potential difference in force of impact. Where *I* stands for relative intensity of the amplitude and g is the $9.81 m/s^2$ the device was recording. The maximum g recorded was 2.38 g and this value was used to standardize the data in a way to compare wave intensities between frontal and side impacts. Multiplying by ten standardized the data further to make reading comparisons easier without skewing the results.

$$I = (g \text{ of point}/2.38g) * 10 \qquad \textbf{Equation 2}$$

Each impact was record using LabView and converted to Excel Word program for analysis. The data of each point set was combined in a three dimensional graph to present change of intensity over distance away from the initial impact point on the helmets exterior and is recorded in the result section below.

CHAPTER 3

RESULTS AND DISCUSSION

Images of the helmets, before and after multiple collisions reveal changes in morphology of the polycarbonate materials. Figure 7 below illustrates a helmet before impact with minor imperfections on the shell of the helmet. After multiple impacts imaging from the LC-SEM provides evidence of damage to the surface of the helmet Figure 8. The damages viewed suggest possible diminished protective capacity. The damage is localized; therefore the impact does not significantly propagate along the surface of the helmet to divert impact away from the brain.

Figure 7. Minor defects observed on helmet before multiple impacts

Figure 8. Observed damage of helmet surface after multiple impacts

Choosing the most likely impact points, three accelerometers recorded wave propagation and readings were amalgamated to track total progression throughout the helmet. Figure 9 below demonstrates the progression of a single impact after data was standardized for the frontal propagation of the helmet in terms of intensity versus distance away from initial impact point. The Z axis on the graph represents the position the accelerometer had on the helmet grid. The legend (1-14) also represents the position on the grid in reference to figure 1. As expected the curve follows the shell of the helmet traced by the red line. Figure 10 includes the z-axis to reveal position along the helmet is curved. The graph reveals relatively high single peaks of waves along the surface of the helmet with damp lower peaks going into the helmet. This suggests some deterring of waves acting within the cranial space. The graph also indicates the highest peak presenting itself directly behind the head from the frontal impact. When the waves travel along the helmet shell they combine behind the head into one large peak.

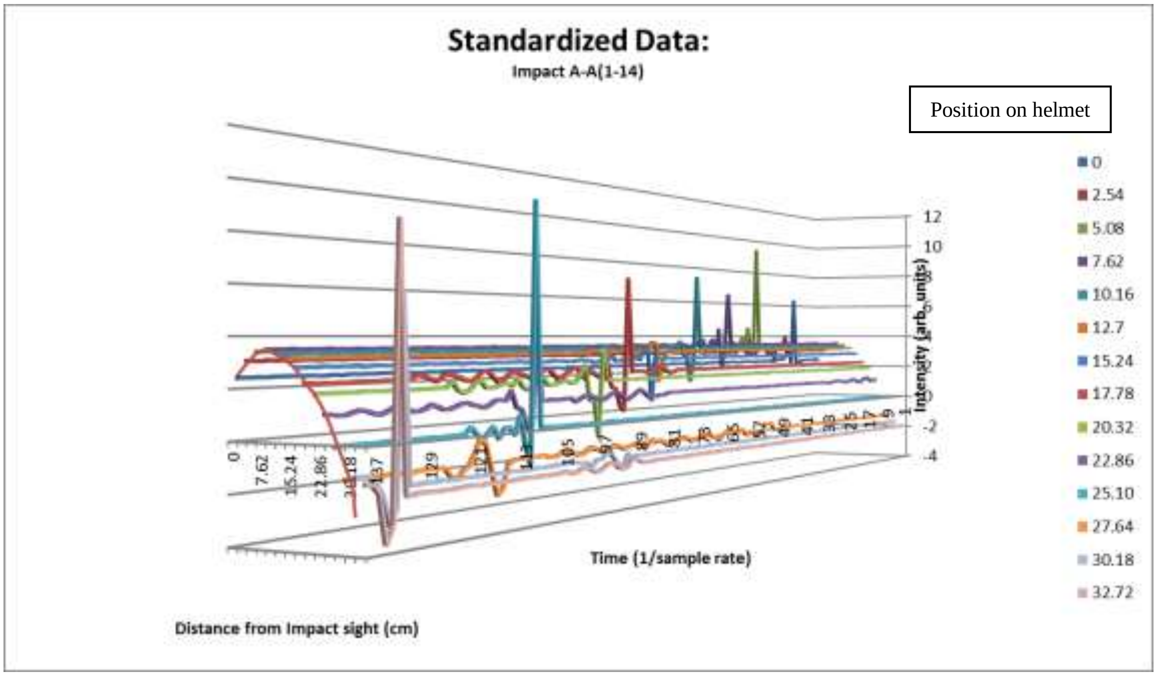

Figure 9. Standardized data of frontal impact propagation of plots along the A longitudinal line.

The side propagations demonstrate more of a vibrational pattern as opposed to the frontal single peak impact waves a**s** observed in Figure 10. The graph is also represented in a similar way to figure 9; where the Z-axis of the graph demonstrates its position on the helmet grid referring to the transverse lines. This could result in more waves interacting with brain. However, the peaks are relatively lower when compared to the frontal impact. Therefore, while more chance for waves causing a concussion, they are of a lower intensity. Perhaps this will lessen the impact of the overall injury. Similar to the frontal impact the side impact resulted in a higher wave peak on the opposing side of the initial impact. Identifying ways to prevent this effect could prevent future injury.

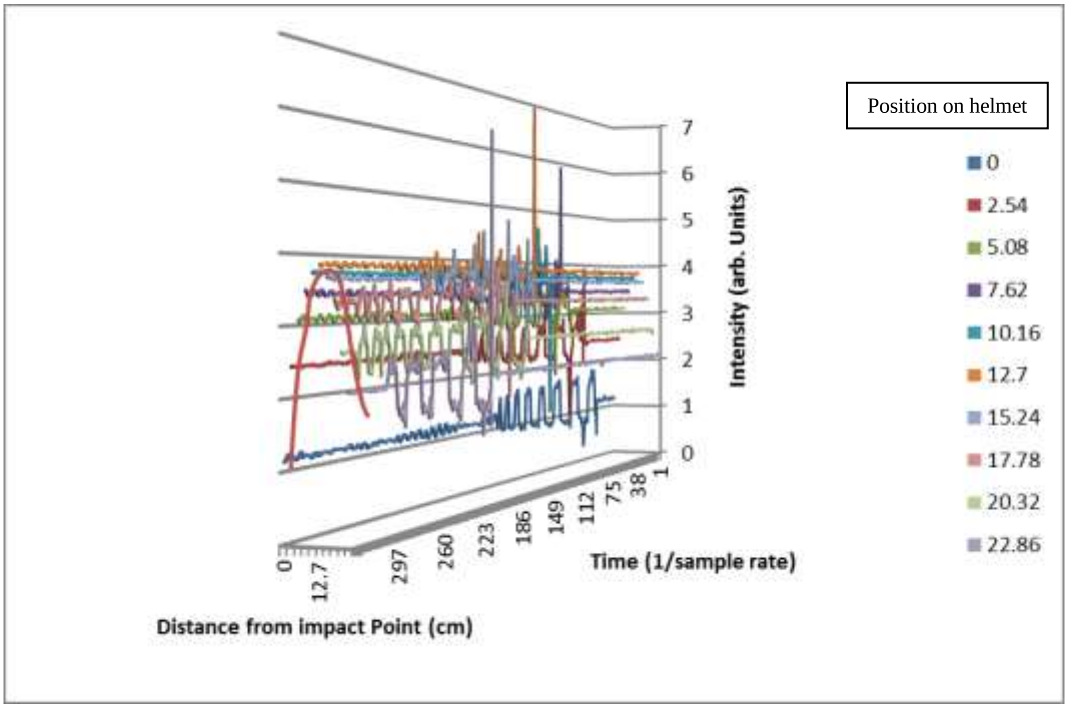

Figure 10. Side impact standardized data of transverse plots along the G line on the helmet.

Overall, the data reveal that despite efforts to prevent concussions wave propagation and vibrational patterns were still observed along the shell of the helmet. Side impacts have lower intensity reading, but more vibrational peaks, while frontal impacts have higher single peaks. The LC-SEM reveals clear damage to the surface of the helmet after multiple impacts. How this may mitigate or intensify the wave peaks. Since this comparison is unclear, these findings could provide a basis for future perspectives of analysis.

CHAPTER 4

CONCLUSION

The results of this investigation are a first step in developing a sound basis for further measurements and could provide new insights into the construction of improved protective headgear in sports. This has the potential to impact the medical community, as a more thorough understanding into the nature of the materials of protective headgear is explored. Comprehension of the manner in which the brain is impacted after multiple collisions is pertinent to concussion prevention. Accelerometers monitoring the vibrations from a controlled impact should be used to study the evolution of the wave developed on helmets after collisions. However, this strategy can be expanded to new experiments for even more clear conclusions.

For example, as an approximation, an artificial “brain” can be constructed of Jell-O (or similar) surrounded by a sealed flexible latex membrane (similar to a water balloon) to further study the effects on the brain specifically. Accelerometers should be placed on longitudinal and transverse directions relative to the front of the helmet, as well as on a dummy-head or other head like structure with the simulated brain on the inside. Recorded vibrations can be used to study the manner in which the impact waves are propagated within the brain to better understand concussion prevention. Recording how the waves interact with the cranial space specifically could result in more conclusive research.

Further, studies using a more controlled impact mechanism should be used to develop more meaningful results. The studies used for research in this report illustrated an impact rod mechanism that provided impacts with less differentiation in force. More controlled force would further limit error in experimental data. However, the limitation of resources prevented this technique for being utilized here. Also, studying wave differentiation before and after multiple impacts occur could result in a better understanding of the overall integrity of a helmet. As the helmet endures more impactful waves, understanding wave propagation in regards to change in morphology could give more empirical results on when to replace equipment. Also the utilization of more accelerometers along the helmet could provide solidified data with less margin of uncertainty.

Finally, comparing the impact waves on the Xenith helmet could provide insight into which material is better to use. The new Xenith helmet manufactured in Lowell, MA should also be tested to compare the inflatable padding and thermoplastic material that can adapt with dependency on the collision (Xenith 2014). This helmet architecture is similar to air bag use in cars. This will theoretically slow down the impact and reduce the force felt by the head. Studying the differences in the architecture between Xenith and Riddell should be researched. Overall, this experiment is successful in tracking the change in wave prorogation and provides a novel perspective for observing helmet-to-helmet collision.

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