Performance Characteristics of a Soccer Head Guard

by

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ABSTRACT

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The purpose of this study was to describe selected performance characteristics of the Full 90 Select soccer head guard. More specifically the ability of the Full 90 Select head guard to attenuate the impact force of a size 5 soccer ball traveling at 8.67 m/s measured after a single impact, after repetitive impacts, and after the head guard had been soaked in water. The soccer ball was dropped onto a force plate or onto the head guard mounted onto the force plate. A video camera recorded the ball drop and impact at 120 images per second. The peak impact force transmitted through the head guard to the force plate was measured. Data from the digitized video recording was used to compute the impact velocity of the ball. The performance of the soccer head guard was also evaluated using impact tests specified by the NOCSAE standards for certifying lacrosse helmets. In these tests the head guard was mounted onto a head form, dropped from heights of 30, 48, and 60 inches, and the peak resultant acceleration and severity index was measured.

The head guard significantly decreased the impact force of the dropped soccer ball both in the wet and dry conditions and after repetitive impacts. The severity index and resultant accelerations measured during the NOCSAE tests exceeded the maximums established by NOCSAE and the head guard did not pass these tests.

It was concluded that soccer head guards may be a way of reducing head injuries in soccer but more testing needs to be done to evaluate the performance of these head guards during minor and severe impacts. Consequently, the overall performance of this head guards was effective in attenuating the multiple impacts and well as impacts while

wet, Yet when the head guard was subjected to more severe impacts while on a head form it showed minimal effectiveness in protecting against severe head injury.

ACKNOWLEDGEMENTS

Throughout this process and leading up to the completion of this study it would be impossible to mention and recognize all of those who have helped and contributed along the way. Though I must take time to recognize some of the people without whose determination, patience, and guidance this would have never been completed.

The Exercise Science and Sport Studies Department at SUNY Cortland as a whole was supportive and played and crucial role, particularly Peter McGinnis, Joy Hendrick, and Jeff Bauer without whom this project would have never happened. Throughout all the research, data collection, and editing they never lost sight of a successful completion. This project has been greatly enhanced by the collective contributions of these three outstanding professionals.

A special thanks to Jason Allen, Dean Moran, and Intertek ETL Semko for the use of their helmet testing facility in Cortland, New York as well as their assistance with impact testing and data collection.

Finally, I would like to thank my family, for providing me with every opportunity to be or do anything I ever set my mind to, for never allowing me give up, and for always showing me love and support.

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CHAPTER 1

INTRODUCTION

Within the sport of soccer there is a growing concern for the safety of the participating athletes. One of the main concerns is the reported incidence of head trauma to large numbers of players from beginners to professionals. Tysvaer, Einar and Lochen, (1991) have shown that repetitive heading or other trauma to the head such as head to head impacts or head to ground impacts, may lead to neurological brain dysfunction. How can soccer be made safer without changing the nature of the game?

One proposed solution is the use of protective head guards by soccer players. Foam padded head guards such at the Full 90™ Select have been developed to reduce the repetitive forces shown to cause injury over time to participating athletes. The purpose of the head guards is to reduce the risk of injury by diminishing the blow taken by the head during impacts with the ball, another player's head, the goal post, or the ground. Reduction in the force of impact reduces the acceleration of the head and brain and thus reduces the risk of brain injury.

The use of soccer head guards raises several questions about the performance characteristics of the head guards. How well does the head guard attenuate ball impact forces? Does the ability of the head guard to attenuate ball impact forces diminish after multiple impacts? Does the ability of the head guard to attenuate ball impact forces diminish when the head guard is wet? How does the head guard compare to a lacrosse helmet when impact tested according to NOCSAE standards?

Statement of the Problem

The purpose of this study was to describe selected performance characteristics of the Full 90™ Select head guard.

The specific purposes of this study were to:

1. Measure the force attenuating properties of a Full 90™ Select soccer head guard when impacted by a size 5 Adidas soccer ball traveling at approximately 8.67 m/s (+/- 0.38 m/s).
2. Determine if the force attenuating properties of a Full 90™ Select soccer head guard change with repetitive ball impacts.
3. Determine if the force attenuating properties of a full 90 Select soccer head guard change when the head guard was soaked in water for 4 hours.
4. Determine the impact performance characteristics of a Full 90™ Select soccer head guard when the head guard was impact tested in accordance with the NOCSAE standard for lacrosse helmets.

Delimitations

This study was delimited by the following:

1. Testing was done using a large size Full 90™ Select soccer head guard.
2. Testing was done using a regulation size 5 Adidas soccer ball.
3. Testing was done using realistic ball speeds in both the multiple drop test and wet conditioned test procedures.
4. A Bertec force plate and Peak Motus motion analysis system were used to measure peak impact forces and ball velocities.

5. NOCSAE standards were followed to compare the soccer head guard's impact performance characteristics with that of a lacrosse helmet.

Limitations

This study was limited by the following:

1. The force plate used to measure peak impact forces was flat and did not have the same shape or physical characteristics of a real head. Therefore, peak impact forces measured by the force platform may differ from the impact forces acting on the head during impact with the ball for the same ball velocity and head guard condition.
2. The mechanism used to control the drop of the ball in the multiple impacts and wet conditioned test procedures produced a small friction force, thus, slightly altering the free fall condition of the ball and its impact with the head guard on the force platform.
3. Only 3 head guards were tested in this study. One in the repetitive impact test, one in the conditional impact test, and on the in NOCSAE test.
4. The use of NOCSAE standards for certifying lacrosse helmets was used due to the availability at the ETL testing facility in Cortland, New York.

Significance

The significance of this study is that it will provide the public with information about some of the performance characteristics of the Full 90™ Select soccer head guard. Someone who uses a soccer head guard or who buys a head guard for someone else to use, may believe that the head guard will fully protect the wearer from the possibility of head injury. This study will provide the user with specific information about the performance characteristics and possible limitations of the Full 90™ Select soccer head guard.

Hypothesis

The following hypothesis was postulated:

The Full 90™ Select soccer head guard will show minimal shock absorbing characteristics. More specifically, it was hypothesized that:

a. There will be no significant difference in peak impact force on the force platform when dropping a soccer ball onto the soccer head guard mounted on the force platform compared to dropping a soccer ball onto the force platform with no head guard present.
b. There will be a significant increase in the impact force transmitted to the force platform through the soccer head guard over the course of multiple impacts by the dropped soccer ball
c. There will be no significant difference in peak impact force on the force platform when dropping a soccer ball onto the wet conditioned soccer head guard mounted on the force platform compared to dropping a soccer ball onto the force platform with no head guard present.
d. The Full 90™ Select soccer head guard will not pass the NOCSAE lacrosse helmet impact test.

Rationale for Hypothesis

Increased awareness about head injuries in the game of soccer has led to the development of products designed to increase the level of protection for the participating athletes. The ability of these new products, specifically the Full 90™ soccer head guard, to perform as advertised is the focus of this study.

Repetitive impacts have been noted to cause neurological impairments (Lees & Nolan, 1998). The ability of the Full 90™ soccer head guard to attenuate impact forces through repetitive impacts is one concern. Another concern is the false sense of security and protection that an athlete may assume while wearing a soccer head guard. Objective testing of the performance characteristics capabilities of the Full 90™ Select soccer head guard is needed.

Definition of Terms

NOCSAE. National Operating Committee on Standards for Athletic Equipment.

Angular Acceleration. Rate of change in angular velocity

Electroencephalogram. EEG, A measurement of the electrical activity within the brain.

Friction. Force acting at the area of contact between two surfaces in the direction opposite that of motion or motion tendency.

Helmet. A protective device worn on the head in an effort to reduce or minimize head injury.

Test area. The area of the helmet on or above a specified line, subject to impact or penetration testing.

Accelerometer. A device for measuring linear acceleration.

Summary

The increased awareness of the prevalence of head injury in soccer has led to the development and use of soccer head guards to decrease the severity and multitude of head trauma related to heading in soccer. Protective soccer head guards were developed to decrease the impact forces placed on the head during activities such as heading the ball or coming in contact with another player or surface. The ability of these foam padded soccer head guards to effectively attenuate impacts placed on the head is questionable. It was hypothesized that with repetitive impact testing, wet conditioning, and head guard impact testing using the NOCSAE lacrosse helmet standard, this particular form of soccer head guard would be deemed ineffective in attenuating the forces placed on the head that cause neurological impairment.

CHAPTER 2

REVIEW OF RELATED LITERATURE

The interest in sports injury surveillance and awareness has grown through the years, along with research and experimentation on the injuries that occur in the game of soccer. Soccer injury research has focused on lower leg injuries, upper extremity injuries, and trauma to the head. The focus of the present study is the use of a protective head guard in soccer competition. The purpose of the head guard is to lower the risk of injury to the head by decreasing the magnitude of the impact forces to the head. Previous research, has shown that head injuries accounts for 4 to 22% of all injuries in soccer (Tysvaer, 1992). Concern has grown for the severity and effect these injuries have on players' immediate and long term neurological function. This chapter reviews the research literature concerned with: head injuries in soccer (including frequency, causes, and symptoms), ball velocities encountered in soccer games, and methods used to investigate the performance characteristics of soccer head guards.

Head Injuries in Soccer

Barnes et al. (1994) reported that in a sample of 72 active players, 89% has experiences some kind of head trauma, while some were acute and others more serious, the focus is on the cumulative effective of these injuries. (Barnes, McDermott, Cooper, & Garret, 1994). Severe brain injuries can occur at low levels of impact especially if the impacts are repetitive, such as in heading a soccer ball (Tysvaer, 1992). Comparisons have been made between the dementia that boxers suffer after their careers and the head trauma experienced by soccer players following participation in practices and games over an approximate 10-year career (Jordan, Green, Galanty, Mandelbaum, & Jabour, 1996).

Repetitive minor impacts such as heading the ball can result in injuries of great magnitude, thus the number of headers per practice session and throughout a season should be observed. Jordan et al. (1996) estimated that the average number of heading exposures an athlete experiences is 11.8+/- 6.9 (range, 5 to 20) headers in one practice session, and 102 +/- 67.3 (range, 26.3 to 272) headers in a season. Even if the impact is less than substantial to cause immediate damage, repetition of such small impacts can cause damage over time. (Jordan et al., 1996). The damage done to the brain and its structures is comparable to that from a concussion.

A concussion can be defined as: "a clinical syndrome characterized by immediate and transient posttraumatic impairment of neural functions-such as alterations of consciousness, disturbance of vision, and loss of equilibrium due to brain stem damage (Prentice, 2006). Signs and symptoms of a concussion differ for every individual who suffers one. Yet, there are certain symptoms most often identified such as blurred vision, dizziness, headache, difficulty concentrating, amnesia, and or memory loss (Guskiewicz, Weaver, Padua, & Garrett, 2000; Harmon, 1999). With head injuries accounting for approximately 4-22% of injuries in soccer, the use of protective equipment to decrease the frequency of injuries should be considered and the effectiveness of the protective equipment should be evaluated (Tysvaer, 1992). The primary concern is that repetitive blows coming from heading the ball, whether sustained in practice or games, is the main cause of minor brain traumas. Repeated mild traumas to the head may result in EEG abnormalities; most likely due to minor impacts causing permanent neuronal damage, decrease in memory, planning, and IQ test scores (Tysvaer, Odd-Vebjorn, & Storli, 1989; Queen, Weinhold, Kirkendall, & Yu, 2003). These neurological impairments have raised concerns. Efforts have expanded to study and measure the severity of impact forces on the head in order to reduce the number and severity of head injuries that result in these neurological impairments (Jordan, Green, Galanty, Mandelbaum, Bradley & Jabour, 1996).

Rapid head and brain acceleration and decelerations are the cause of most head and brain trauma (Cantu, 1998). When a ball strikes the head of an individual playing soccer, the skull accelerates and decelerates, causing the brain to stretch and twist unnaturally (Naunheim, Bayly, Standeven, Neubauer, Lewis, & Genin, 2003). Heading is a combination of both linear and angular accelerations that are transmitted to the head and brain. Angular accelerations are said to be the more damaging of the two, disrupting the fluid-like character of the brain (Naunheim et al., 2003). The brain is able to sustain higher levels of linear accelerations due to the brain's inability to compress. With angular accelerations brought on by such things as heading a ball, the large rotational forces placed on the brain can cause physiological changes and injury (Naunheim et al., 2003). Technique has a large effect on the size of the impact forces transmitted to the brain while heading a soccer ball. Improper heading technique has been associated with headaches and in some cases amnesia in 32% to 43% of players in elite competition (Queen, Weinhold, Kirkendall, & Yu, 2003). Improper heading techniques have been shown to increase impact forces significantly leading to head and brain injury (Barnes, Cooper, Kirkendall, Mcdermott, Jordan, & Garrett, 1998). This is not only a concern for the older or professional population playing soccer, but also to the youth groups participating.

Head mass and ball size do affect the linear and angular head acceleration and contact time (Lees & Nolan, 1997; Queen, Weinhold, Kirkendall, & Yu, 2003). The use of smaller ball sizes for youth groups would decrease linear and angular head accelerations and therefore decrease the risk of injury (Lees & Nolan, 1997; Queen, Weinhold, Kirkendall, & Yu, 2003). The major contributing factors to head injuries in soccer are: poor heading technique leading to increased linear and angular head accelerations, and younger age groups suffering from injury due to inappropriate ball size for youth participants.

Ball Velocities in Soccer

Ball speed plays a large role in the severity of impact forces on the head during contact. There are a variety of different ball speeds that occur throughout the game of soccer, in both youth and adult levels. Lees and Nolan (1998) compared the ball velocities of younger soccer players (8-17 years old) to the ball velocities of adult soccer players. Ball velocity of the younger players was significantly lower than that of the adults. Maximum ball speeds for these younger individuals of 8-17 years of age were reported to reach up to 12.0-15.5 m/s. Lees and Nolan (1998) also reported that younger individuals between 10-17 years of age have ball velocities reaching 15.0-22.0 m/s (Lees & Nolan, 1998). This would make it appear that as skill level and age increases so would ball speeds.

In 2003, Bray and Kerwin presented a study to model ball flight. They recorded ball velocities ranging from 17.9-28.3 m/s. These velocities were recorded in observation of free kick maximum ball velocities and do not resemble the same velocities being used in the present study. They are used to show the magnitude that ball velocities can reach in elite soccer competition. In another study, McKean and Tumilty (1993) compared the difference in left vs. right side and dominance, by observing ball velocity. The mean ball velocity measured for kicks by the dominant leg was 79 km/h. The mean ball velocity measured for kicks by the non-dominant leg was 66 km/h. Elite Australian junior soccer players with an average age of 16.8 year were the subjects in the study. Their recorded velocities may be slightly higher than that of the average players in this age group (McLean & Tumilty, 1993).

The average ball velocities reported in the literature show a variety of achievable ball speeds through a variety of age groups. This information was used in determining the ball velocity to be used in the present study. An impact velocity well below maximum ball speeds seen in soccer in both youth and professional levels was chosen. This was done to determine if multiple impacts to the head guard by slower balls would cause breakdown within the head guard, thus affecting its impact attenuating capabilities. Does the head guard have the ability to attenuate repetitive forces placed on the head by a ball at low velocity over multiple trials and perform consistently?

Performance Characteristics of Soccer Head Guards

Standard for testing the performance of soccer head guards have begun to be analyzed and calculated by agencies such as NOCSAE and ASTM, and investigations of the performance characteristics of the Full 90™ head guard have been completed. Full 90™ Sports (2003) reported the results of a study conducted at North Dakota State University. This study was done to observe the rebound characteristics of the head guard and its effect on performance in heading situations to see if there was a negative effect when wearing the head guard. Soccer ball rebound speeds from a head protected head by a Full 90™ head guard vs. an unprotected head were compared. Through testing a variety of speeds ranging from 6 mph to 43 mph, the protected head and unprotected head showed no signs of significant difference in rebound speed. The study showed that a soccer ball rebounds from the Full 90™ protected head at the same speed as it does off an unprotected head. Rebound speed was lower than incident speed, but it was lower in both the protected and unprotected conditions by the same amount. This shows that the speed of play will not be affected when in a heading situation. What it also shows is that the head guard shows no characteristics of slowing ball speeds upon impact with the head to reduce possible impact forces that can cause injury during soccer competition (Full 90™ Sports, 2003).

Other soccer head guards are available to the public. Their manufacturers make claims that the head guards will effectively reduce the amount of impact force a ball places on the head so as to reduce head injury. The other models available in the United States are Kangaroo™, Head Blast™, Soccer Docs™ and Head r'™. Naunheim (2003) tested these different head guards, using 22, 26, and 34 mph ball speeds at impact. These are ball speeds typically encountered in high school level of competition. Regulation-sized soccer balls were impacted against a magnesium headform, which was attached to a semi-flexible rubber neck. Naunheim found no significant differences in impact forces to the head while wearing any of these head guards compared to the no head guard. Naunheim suggested that wearing of these protective head guards will not reduce the risk of head injuries. He recommended educating young players to reduce the amount of heading or to not head the ball at all at a younger age (Naunheim, 2003).

Summary

Head injuries are not the most prevalent soccer injury yet they are the most damaging. Even repetitive minor impacts to the head can cause considerable long-term damage to neurological function (Jordan, et al., 1996). Rapid accelerations and decelerations of the head caused by heading a soccer ball can result in impairment of normal brain function (Tysvaer, 1992). The impact forces which cause the rapid accelerations and decelerations of the head when heading a soccer ball are affected by several factors including the speed and size of the ball as well as the technique used to head the ball. Previous studies reported soccer ball maximum velocities in both competition and practices that are faster than the velocities used in the present study.

There are other studies that have been done to test the performance characteristics of soccer protective head guards. These studies concluded that protective soccer head guards cannot significantly attenuate impact forces of balls impacting at speeds typically seen in high school levels of competition and ranging from 20-34 mph.

Further study of the performance characteristics of protective soccer head guards and more widespread public dissemination of information regarding these characteristics of soccer head guards are needed.

CHAPTER 3

METHODS AND PROCEDURES

The purpose of this study was to describe selected performance characteristics of the Full 90™ Select head guard. The specific purposes of this study were to:

1. Measure the force attenuating properties of a Full 90™ Select soccer head guard when impacted by a size 5 soccer ball traveling at approximately 8.67 m/s (+/- 0.38 m/s).
2. Determine if the force attenuating properties of a Full 90™ Select soccer head guard change with repetitive impacts.
3. Determine if the force attenuating properties of a full 90™ Select soccer head guard change after the head guard was soaked in water for 4 hours.
4. Determine the impact performance characteristics of a Full 90™ Select soccer head guard when the head guard was impact tested in accordance with the NOCSAE standard for lacrosse helmets.

A ball drop test was used to accomplish the first three purposes while the NOCSAE drop test methods for lacrosse helmets were employed to accomplish the last purpose. Peak impact force was measured in the ball drop test and peak acceleration of the headform was measured in the NOCSAE test.

Ball Drop Test Methods

The general procedure used to accomplish the first three purposes was to drop a size 5 soccer ball from a height of 4.67 m onto a force platform or onto the frontal area of a wet or dry Full 90™ Select soccer head guard mounted onto a force platform and measure the peak impact force transmitted to the force platform. The order of testing was as follows:

Control test: The soccer ball was dropped onto a force platform three times in a row and the peak impact force from each of these drops was recorded.

Multiple impact test: The soccer ball was dropped onto a Full 90 Select soccer head guard mounted onto the force platform 15 times in a row and the peak impact force from each of these drops was recorded.

Wet-conditioned test: The soccer ball was dropped onto a wet Full 90™ Select soccer head guard mounted onto the force platform five times in a row and the peak impact force from each of these drops was recorded. Prior to this test, the head guard was submerged in room temperature water for a period of four hours.

The three tests (control, repeated impact, and wet-conditioned) were repeated on three consecutive days. The peak impact forces from these conditions were then compared to determine if any differences existed between the three conditions and between the three days.

Experimental Apparatus for Ball Drop Tests

The area of the targeted impact zone on the head guard was small. To insure that the ball impact occurred in this area for all trials and to insure that the impact velocity was similar for all trials, an apparatus was constructed to consistently release a size 5 soccer ball from the same height and location so that it dropped onto the targeted frontal portion of the head guard.

The apparatus consisted of a pulley (Vernier super pulley), fishing line (Spectra Spiderwire 6 pound test diameter, 30 pound test weight), and bait casting reel (Daiwa

TriForce-X 153iV). The fishing line was attached to the thread of the soccer ball. The pulley was mounted directly above the force platform to an overhead support and remained stationary throughout testing. The fishing line was connected to the soccer ball and drawn over the pulley. To insure that the ball was released from the same height in each trial, two struts were attached to the overhead beams and the ball was reeled up until the top of the ball made contact with these struts. In this position the bottom of the ball was 4.67 m above the surface of the force platform. The spool tension of the reel was adjusted to the lowest possible setting so that the reel spun freely. A clutch mechanism in the reel allowed the ball to be held stationary against the struts. The ball was released and began to fall when the clutch was disengaged. The ball suspension and release apparatus are shown in figures 1 and 2.

Figure 1. Ball suspended from pulley.

Figure 2. Fishing reel and ball suspension apparatus.

The head guard was mounted and held in place on the force platform with 25 pound weights (see figure 3). A chalk outline of the head guard was traced onto the force platform and used to keep the position of the head guard consistent between trials and between conditions.

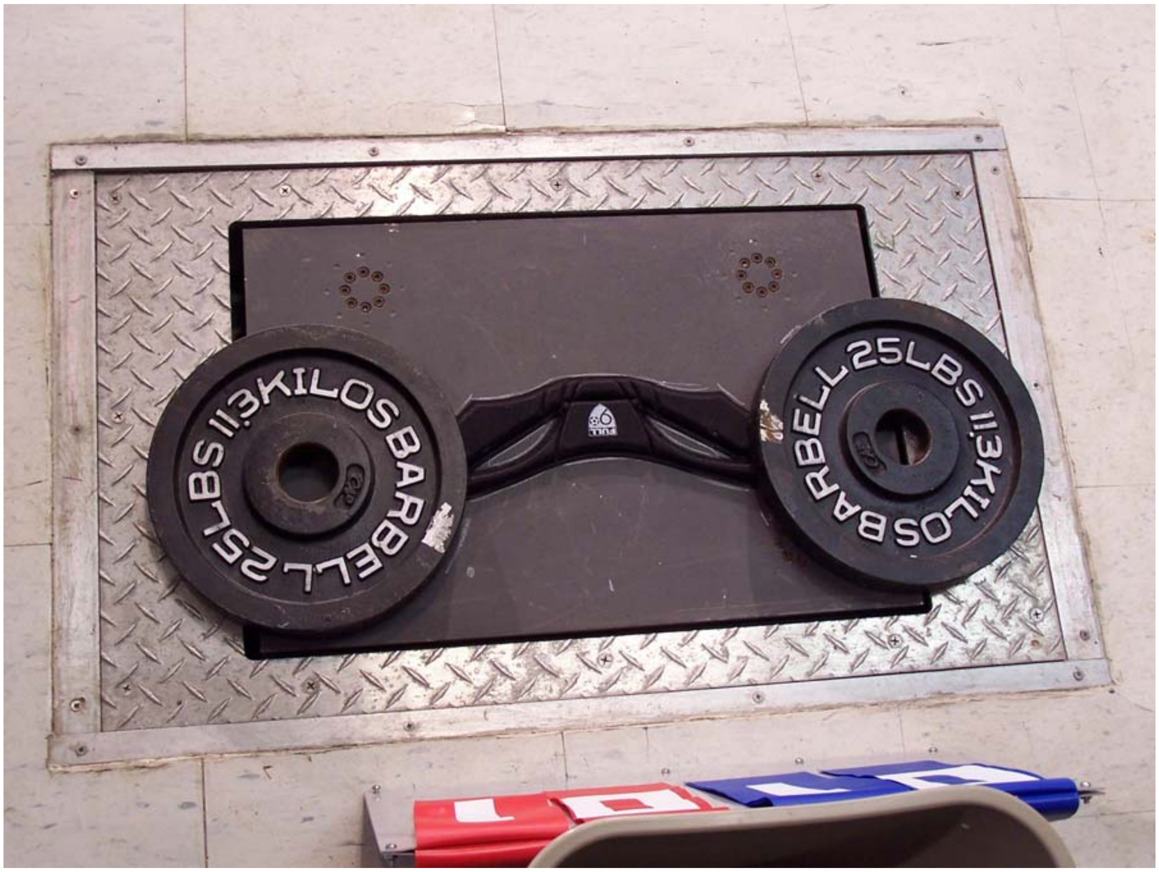

Figure 3. Overhead view of head guard mounted on force platform

Impact Velocity Measurement

The friction and rotary inertias of the reel and pulley imposed a drag force on the ball so that it did not experience a true free-fall. Without this drag force acting on the ball, the impact velocity of the ball with the force plate or head guard would have been 9.57 m/s after a drop of 4.67 m. Because of this drag force, the impact velocity of the ball was slower than 9.57 m/s and had to be determined experimentally using a high speed video camera. A JVC™ GR-DVL9800 ™ mini-DV video camera was used to record the fall of the ball. The camera was mounted on a tripod 6.5m away from the center of the force platform and its shutter speed was set at 1/250th of a second. The camera was set up to record two images per video field at 60 fields per second allowing for a recording speed of 120 images per second. The reference measure used to analyze and digitize the velocities of the ball was one meter in length.

Clips of the appropriate recorded video were captured by a Peak Motus motion analysis system. The endpoints of the one meter reference measure were digitized to determine the pixel to meter conversion. The impact velocity of the ball was determined by digitizing the center of the ball in the two pictures immediately prior to ball impact with the force plate. The displacement of the ball between these two pictures was computed from the digitized positions of the ball and digitized length of the reference measure. This displacement was then multiplied by the effective frame rate (120 pictures per second) to determine the velocity of the ball just prior to impact.

Peak Impact Force Measurement

A Bertec force platform and the Peak Motus motion analysis system were used to measure the peak impact force transmitted to the force platform by the soccer ball. The sampling rate of the force platform was 99,960 Hz. Prior to each impact, the manual offset was taken to account for the weight of the head guard and 25 pound weight plates. Data collection was triggered when the channel corresponding to the vertical force exceeded 5 mV. The pre-trigger time and post-trigger times were 0.10 s yielding a total data collection time of 0.20 s. The resulting vertical force-time curve was immediately viewed in the analog data acquisition window of the Peak Motus system (see figure 4). The window was zoomed to magnify the peak vertical force. The value of this peak force was then manually recorded.

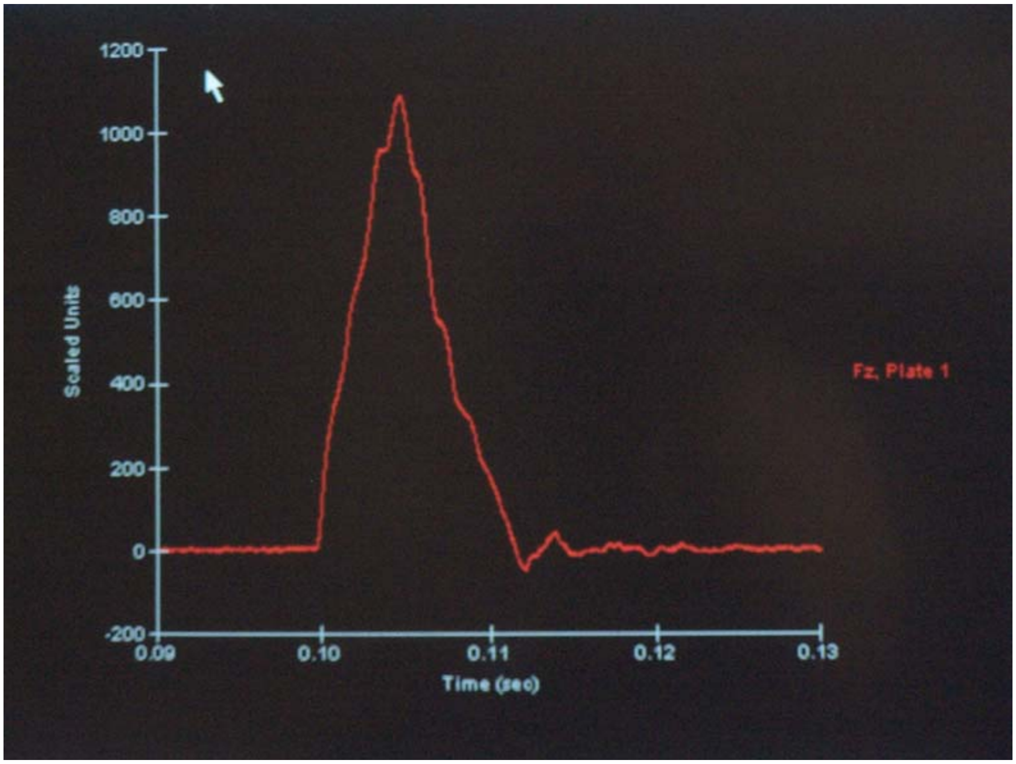

Figure 4. Example of impact force record from Peak Motus system.

Ball Drop Testing Protocol

Ball drop testing occurred over three consecutive days with the same order of testing repeated on each day. Testing began at the same time on each day. Three control impacts were recorded first by dropping the regulation size 5 Adidas™ soccer ball onto the force platform with no head guard present. The head guard was then mounted onto the force platform and 15 repeated impacts of the soccer ball onto the head guard were recorded. The approximate interval between impacts was 75 seconds. The dry head guard was then removed from the force platform and the wet conditioned head guard was mounted on the force platform and impacted within a minute of removal from the conditioning environment. Five repeated impacts of the soccer ball onto the wet-conditioned head guard were then recorded. Between each of these impacts, the wet-conditioned head guard was removed from the force platform and submerged in water for a period of three minutes before it was again mounted onto the force platform. A summary of the ball drop test schedule in shown in Table 1.

Table 1. Schedule of Ball Drop Tests

Day 1	Day 2	Day 3
3 control drops onto force platform	3 control drops onto force platform	3 control drops onto force platform
15 repeated drops onto dry head guard	15 repeated drops onto dry head guard	15 repeated drops onto dry head guard
5 repeated drops onto wet conditioned head guard	5 repeated drops onto wet conditioned head guard	5 repeated drops onto wet conditioned head guard

Each trial began by starting video camera recording via remote control. Using the Peak Motus analysis system, the force platform output was then set to zero and the force platform trigger was set. The clutch of the reel was then manually released and the ball dropped. Two experimenters visually determined the general impact location of the ball on the head guard. The recorded vertical force-time curve was then examined and the peak vertical force determined. These peak force and impact locations were then manually recorded. The one meter reference measure was then recorded in the plane of the centerline of the force platform while the ball was reeled up to its 4.67 m height above the force platform. The video camera recording was stopped while the head guard position on the force platform was checked. The recorded force history on the Peak Motus system was cleared and the procedure was repeated for the next impact.

Wet-conditioned Testing Protocol

The conditioning treatment of the head guard involved fully submerging the head guard in water to simulate that of a rain soaked or sweat soaked apparatus. This four hour submersion followed ASTM International standards for helmet testing. Once removed from the conditioned environment NOCSAE standards specify the first impact shall occur within the first minute after being removed from the conditioning environment. The second impact occurred after a three minute conditioning treatment where the head guard was placed back in the water. This was done so if impact of the head guard dispersed any water from the head guard, the amount of saturation of the head guard stays consistent. After the five wet-conditioned impacts, the head guard was allowed to dry for approximately 20 hours and then the head guard was again submerged in water for a period of four hours prior to the next testing session. A summary of the wet conditioned impact test schedule in shown in Table 2.

Table 2.Wet Conditioned Impact Schedule

Day 1	Day 2	Day 3
4 hours submerged in water	4 hours submerged in water	4 hours submerged in water
5 impacts each separated by 3 minutes of submersion in water	5 impacts each separated by 3 minutes of submersion in water	5 impacts each separated by 3 minutes of submersion in water
20 hours in dry environment with no impacts	20 hours in dry environment with no impacts	

NOCSAE Lacrosse Helmet Impact Test Method

The final purpose of this study was to determine the impact performance characteristics of a Full 90 Select soccer head guard when the head guard was impact tested in accordance with the NOCSAE standard for lacrosse helmets as described in NOCSAE DOC (ND) 041- 04m04b and NOCSAE DOC (ND) 001- 04m05. The NOCSAE impact testing of the soccer head guard took place at the ETL laboratory in

Cortland, New York. Only one impact location was used instead of the six locations specified in the NOCSAE standard. Only the frontal region of the soccer head guard was impacted (see figure 5). The drop heights used were 30, 48, and 60 inches in accordance with NOCSAE standards. Testing was done to measure both the severity index and the peak resultant acceleration of the head form during the impact.

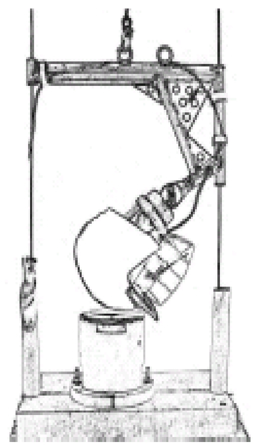

Figure 5. Helmet on head form mounted to drop test apparatus for frontal impact test. (NOCSAE DOC 041-04m04b)

The Full 90™ Select head guard was fit snuggly to the large NOCSAE head form and was held firmly by the head guard’s adjustable Velcro straps in the posterior region of the head guard. The head form and head guard were then dropped from a height of 30, 48, or 60 inches onto a calibrated MEP pad. A tri-axial accelerometer located at the center of gravity of the NOCSAE head form measured resultant acceleration of the headform during the impact. The time history of the acceleration data was used as input to an online computer which computed the severity index for the impact. A dual wire dropping mechanism was used in accordance with NOCSAE specifications (see figure 6).

The NOCSAE standard for required lab temperature is required to be 72.0º F +/- 5º F (22º C +/- 2º C).

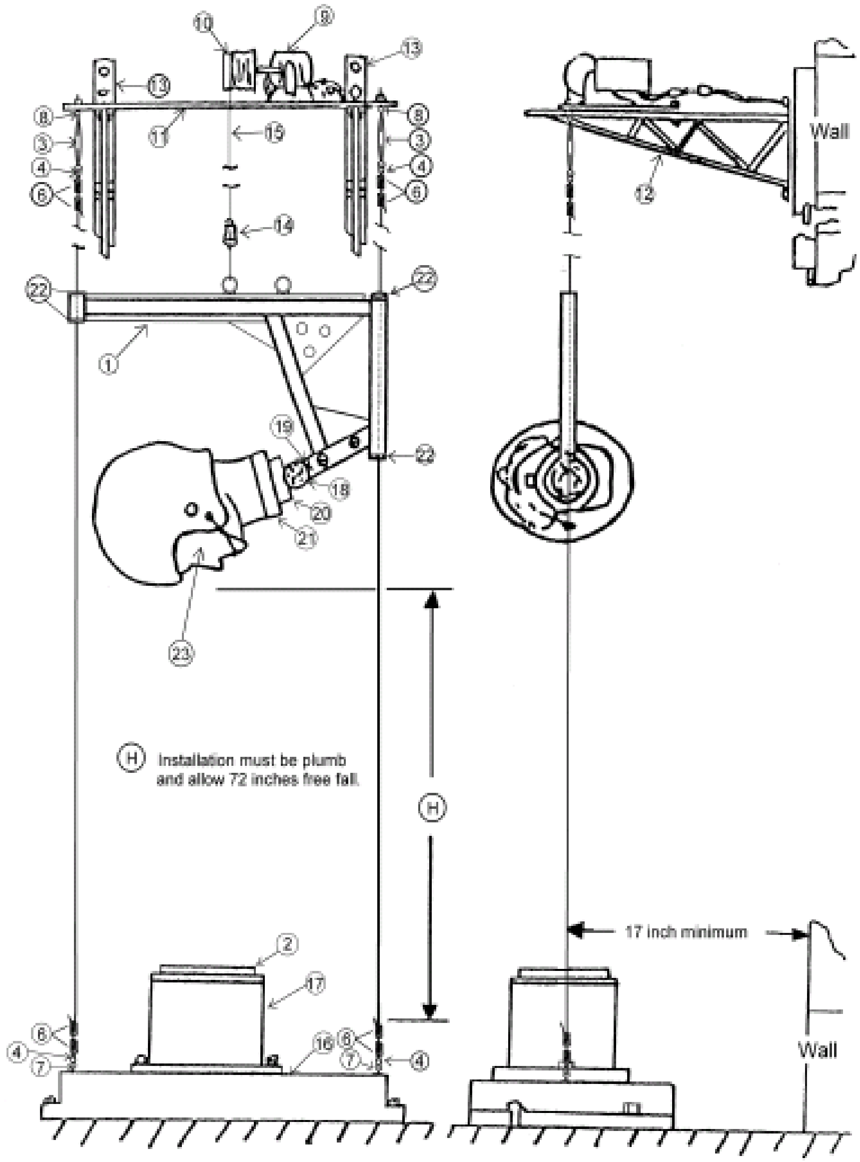

Figure 6. Diagram of NOCSAE dual wire drop test apparatus for impact testing helmets. (NOCSAE DOC 041-04m04b)

Data Calculation and Analysis

The peak force data recorded for the ball drop tests (the control test, the repeated impact tests and the wet-conditioned tests) were compared and analyzed using SPSS for Windows, a statistical analysis program. Descriptive statistics for the peak impact force data for the three conditions and three days were computed. The data were then analyzed using a 3 x 3 mixed ANOVA to identify if any significant differences among the three test conditions and three days existed. A Tukey HSD post-hoc test was then done to examine the significant differences found by the ANOVA. In all the procedures an alpha level of .05 was used to test for significance.

The head guard was also put through the testing protocol for certifying men's lacrosse helmets by NOCSAE standards. The results from this testing were compared to the maximum severity index and maximum acceleration values allowable according the NOCSAE standard for lacrosse helmets.

Summary

A ball drop test repeated multiple times over three consecutive days was used to determine certain performance characteristics of a Full 90 Select soccer head guard including, the force attenuating properties of a Full 90 Select soccer head guard including its force attenuating properties, change in its force attenuating properties as a result of repetitive impacts, and change in its force attenuating properties as a result of water immersion. The Full 90 Select soccer head guard was also impact tested in accordance with the NOCSAE standards for lacrosse helmets to determine the head guard's performance in more extreme impact situations.

CHAPTER 4

RESULTS AND DISCUSSION

Within this chapter, the experimental data collected the Biomechanics lab at the State University of New York at Cortland is presented along with a discussion of some of the results of the procedures and their implications. Within this chapter the following sections will be included: reliability of data, descriptive statistics, experimental findings (with particular attention to ball velocity, average impact force, and NOCSAE impact forces), discussion of results, and general discussion.

Ball Drop Test Results

Before considering the differences in peak impact forces, the impact velocities should be examined. Impact velocities were determined by digitizing the video records of the ball drops. Not every trial was digitized. Only one control ball drop from each day was digitized, the first control ball drop. Four of the repeated ball drops from each day were digitized, the first, fifth, tenth, and fifteenth drops. Two of the ball drops onto the conditioned head guard were digitized, the first and third drops. The means of the measured ball impact velocities are shown in Table 3. The average impact velocity of all the digitized ball drops was 8.67 m/s. This is much slower that the theoretical impact velocity of 9.57 m/s for a free fall from a height of 4.67 m. The slower than predicted impact velocity was due to the friction and inertia of the reel and pulley system used to control the release of the ball and the position of the ball prior to release.

Table 3. Average Ball Impact Velocity

	Control (m/s)	Multiple Impact (m/s)	Conditioned (m/s)
Day 1 Avg.	8.64	8.30	8.82
Day 2 Avg.	9.24	8.52	8.34
Day 3 Avg.	8.64	8.58	9.30
Total Avg.	8.84	8.47	8.82

The peak impact force for the nine control condition ball drops ranged from a high of 1340 N on the second day to a low of 1221 N on third day. The mean peak impact force for the control condition across all three days was 1276 N. The peak impact force for the 45 ball drops on the dry head guard ranged from a high of 1277 N on the second day to a low of 952 N on third day. The mean peak impact force for the normal head guard condition across all three days was 1073 N. The peak impact force for the 15 ball drops on the wet-conditioned head guard ranged from a high of 1158 N on the third day to a low of 934 N on first day. The mean peak impact force for the wet-conditioned head guard condition across all three days was 1073 N. Table 4 presents the average and standard deviations of the peak impact forces for each condition and each day of the ball drop tests. In all cases the mean impact forces for the control were larger than that of both the normal and the wet conditions in all days. There was also less variability within the control group compared to the normal and wet conditions in all days. On average, whether it was wet or dry, the head guard reduced the peak impact force by 16 percent.

Table 4. Means and standard deviations of peak impact forces for ball drop tests (values in N)

Group	Day 1	Day 2	Day 3	Group Mean
Control	1267 * (27)	1325 (25)	1236 (24)	1276
Normal	1061 (56)	1103 (84)	1056 (64)	1073
Wet	1049 (81)	1066 (58)	1104 (61)	1073

A 3 x 3 mixed Analysis of Variance on 3 groups (control, normal, and wet) and 3 days was used to determine if the day of testing or if the test condition had an effect on the peak impact forces. A Tukey HSD, post hoc test was done for a multiple comparison comparing the control to both the wet and normal conditions.

Using this information a test of within-subjects effect was run to see if there was any significant difference between days and groups. After running the within-subjects comparison no significant difference was found in any area showing that as the testing procedures went from day one to day three there were no significant differences in peak impact forces from day to day. The main effect of days was not significant, ($F_{(2,40)}$ = 1.403, p = 0.258). The days by group interaction was not significant, ($F_{(4,40)}$ = 1.042 p = 0.398). Table 5 summarizes the results of this analysis.

Table 5. Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
days	Sphericity Assumed	13132.05	2	6566.028	1.403	0.258
Days* group	Sphericity Assumed	19507.77	4	4876.943	1.042	0.398
Error(days)	Sphericity Assumed	187186.93	40	4679.673		

After comparing the within-subjects effects, a test of between-subjects effects was done to see if there were any significant findings between any of the groups. When a test of between-subject effects was done there was a significant finding. There was a significant difference between group conditions ($F_{(2,20)} = 44.768$, $p < .0001$). This can be seen in Table 6.

Table 6. Tests of Between-Subjects Effects

Source	Type III Sum Of squares	Df	Mean Square	F	Sig.
Intercept	58560176.91	1	58560.176.909	16346.01	.000
group	320768.344	2	160384.172	44.768	.000* sig.
error	71650.729	20	3582.536		

A Tukey HSD Post Hoc test was run to examine the significant findings between the three groups. The Tukey Post Hoc test results confirmed the significant difference between the control groups with both the normal and wet groups. Employing the Tukey post-hoc test, significant differences were found between the control and normal conditions ($p < 0.5$) and between the control and wet conditions ($p < 0.05$). There was no significant difference between the wet and normal conditions (for both, p =.990).

NOCSAE Lacrosse Helmet Impact Test Results

The Full 90™ Select head guard was tested according to NOCSAE standards and procedures for men's lacrosse helmets. The Full 90™ Select head guard was placed on the large NOCSAE head form and dropped from three different heights (30, 48, and 60 inches) onto the frontal region of the head guard to measure the severity index and peak acceleration during impact. Results of these tests appear in table 7. The severity index ranged from a low of 1266 for the 30 inch drop to high of 2500 for the 60 inch drop. In all of the drops the severity index exceeded the peak severity index of 1200 specified by the NOCSAE standard (NOCSAE, 2005). The head guard would thus fail the NOCSAE impact test for lacrosse helmets. The peak accelerations of the headform ranged from 230 g's for the 30 inch drop to 428 g's for the 60 inch drop. In all but the 30 inch drop the peak acceleration exceeded the 300 g maximum acceleration specified in ASTM International standards for most helmets (ASTM International, 2005).

Table 7. Full 90™ Select Impacts

Impact Location	Impact Number	Severity Index	Peak Acceleration (g)
Front	1 (30")	1266	230
Front	2 (48")	2313	354
Front	3 (48")	2315	361
Front	4 (60")	2500	428

For comparison a NOCSAE head form without a head guard was dropped from a height of 30 inches. The results appear in table 8.

Table 8. Bare Head Impacts

Impact Location	Impact Number	Severity Index	Peak Acceleration (g)
Front	1 (30")	1884	292
Front	2 (48")	n/a	n/a
Front	3 (48")	n/a	n/a
Front	4 (60")	n/a	n/a

The results shown in tables 7 and 8 indicate that the head guard produced a reduction of 618 or 33 per cent in the severity index for a drop from 30”, showing practically significant impact attenuation. Yet, peak acceleration was only reduced by 62 g's or 21 percent. The results shown in table 7, show that as the drop height increased, both the severity index and peak acceleration increased as well. Table 7 also shows possible head guard physical breakdown in its ability to attenuate repetitive impacts when looking at the two impacts dropped from the same height twice. The two drops from 48" show a difference in results with the second impact showing a higher result in both categories.

Discussion of Results

The purpose of this study was to test the performance characteristics of a Full 90™ Select soccer head guard. The specific purposes of this study were to:

1. Measure the force attenuating properties of a Full 90™ Select soccer head guard when impacted by a size 5 soccer ball traveling at approximately 8.67 m/s (+/- 0.38 m/s).
2. Determine if the force attenuating properties of a Full 90™ Select soccer head guard change with repetitive impacts.
3. Determine if the force attenuating properties of a full 90 Select soccer head guard change when the head guard was soaked in water for 4 hours.
4. Determine the impact performance characteristics of a Full 90 Select soccer head guard when the head guard was impact tested in accordance with the NOCSAE standard for lacrosse helmets.

Multiple Impact Testing

When comparing the results of a control to the results of a multiple impact drop test, the results showed that the Full 90™ Select head guard was effective in significantly decreasing the impact force. The Full 90™ Select head guard also showed no signs of decrease in ability to withstand the repetitive impacts over the course of 45 impacts. With low intensity multiple impacts the Full 90™ Select head guard was able to attenuate the forces placed upon it and do so consistently.

Wet Conditioned Testing

After comparing the results of a control to the results of that of the wet conditioned impact force results, it was shown that the wet conditioned head guard significantly decreased the impact forces compared to that of a control. After being conditioned in water for four hours and then impacted five times over three days of impact trials, the head guard showed no signs of breakdown or decrease in attenuation capabilities due to being saturated in a water environment. The head guard significantly decreased the impact force placed on it compared to a control and being in a saturated state does not diminish the head guard’s attenuation capabilities.

NOCSAE Testing

It was not hypothesized that the Full 90™ Select head guard would pass or perform as a lacrosse helmet in the NOCSAE procedures. These tests were done to assess the head guard's ability to possibly prevent a catastrophic head injury such as might occur when a head collides with a goal post or another player’s head or knee. The Full 90™ Select head guard was designed to decrease the amount of forces transmitted to the head during soccer competition, more specifically while heading the soccer ball.

The impact testing done at ETL testing facility showed that when a severe impact is experienced by the head while wearing the Full 90™ Select head guard, the head guard would not prevent a catastrophic head injury as indicated by severity indices greater than

1200 and resultant accelerations of the headform greater than 300 g's for almost every trial and drop height. The physical make–up of the head guard consisted of only a thin layer of dense foam material, that when impacted reduced in size significantly. When the thickness of the head guard was reduced once impacted it was evident that impacts such as those seen with the drops at the ETL lab, the head guard would present minimal if any benefit to the one wearing it.

Summary

The Full 90™ Select head guard was effective in significantly decreasing the impact force transmitted to the force plate compared to no head guard. In both the multiple impact and wet conditioned testing procedures the head guard showed similar results. The NOCSAE testing done in ETL lab showed that the Full 90™ Select head guard demonstrated minimal effectiveness in attenuating impacts of more catastrophic nature such as head to ground, head to knee, head to head, or head to goal post impacts. Overall performance of the head guard was effective in attenuating the impact forces placed on it during the ball drop testing in the multiple impact and conditioned testing procedures. Yet, when the head guard was placed in a more severe impact situation, the head guard had minimal protective capabilities.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Injury prevention is a growing concern of all people concerned with athletics and the safety of the participating athletes. It is with this mentality the Full 90™ Select soccer head guard was created. The purpose of the head guard is to reduce the size of the impact forces transmitted to the head and brain that would subsequently cause head injury such as a concussion.

The purpose of this study was to describe selected performance characteristics of the Full 90 Select head guard. The specific purposes of this study were to:

1. Measure the force attenuating properties of a Full 90 Select soccer head guard when impacted by a size 5 soccer ball traveling at approximately 8.67 m/s (+/- 0.38 m/s).
2. Determine if the force attenuating properties of a Full 90 Select soccer head guard change with repetitive impacts.
3. Determine if the force attenuating properties of a full 90 Select soccer head guard change when the head guard was soaked in water for 4 hours.
4. Determine the impact performance characteristics of a Full 90 Select soccer head guard when the head guard was impact tested in accordance with the NOCSAE standard for lacrosse helmets.

A ball drop test was used to accomplish the first three purposes while the NOCSAE drop test methods for lacrosse helmets were employed to accomplish the last purpose. Peak impact force was measured in the ball drop test and peak acceleration of the headform was measured in the NOCSAE test.

Findings

Resulting from the analysis of the video digitizing and force plat form feedback, it was found that:

1. Multiple impact testing showed that the Full 90™ Select head guard was effective in significantly reducing the impact of a size 5 Adidas™ soccer ball traveling 8.67 m/s (+/- 0.38 m/s).
2. Multiple impact testing showed no signs of material breakdown or decrease in performance throughout the course of this study.
3. The wet conditioned head guard was effective in significantly decreasing the impact forces placed on it compared to that of a control.
4. Saturating the head guard in water for four hours prior to impact showed no negative effect on the force attenuating capabilities of the Full 90™ Select head guard.
5. At lower velocities the Full 90™ Select head guard was effective in significantly decreasing the impact force transmitted through to the force platform.
6. During the NOCSAE impact tests for men’s lacrosse helmets, the Full 90™ Select head guard showed minimal effectiveness in protecting against catastrophic head injuries due to head to goalpost, head to head, head to knee, or head to ground collisions.
7. The NOCSAE testing procedures with higher velocities and impact forces produced signs of physical breakdown in the head guard and decreased its attenuating capabilities.

Conclusions

From the results of this study and experimentation, the following conclusions were postulated:

1. At lower velocities the Full 90™ Select head guard decreased impact forces significantly. At an impact velocity of 8.67 m/s (+/- 0.38 m/s) a soccer ball's peak impact force was significantly decreased when a Full 90 Select head guard, wet or dry, was placed on force platform as compared to when a soccer ball impacted the force platform with no head guard present.
2. In a catastrophic or more severe impact situation like those required by the NOCSAE lacrosse helmet test standard, the Full 90™ Select head guard was deemed ineffective. The physical characteristics of the Full 90™ Select head guard, which is comprised of a dense foam material, are not sufficient to protect the head from severe trauma that may occur as a result of head to ground, head to goal post, head to knee, or head to head collisions.

Recommendations for Head Guard Use in Soccer

Some of the areas of consideration for head guards in soccer might include the following concepts:

1. In the game of soccer there are minor impact and severe impact situations that are a part of competitive and recreational soccer. There are head to ball impacts that can be both minor and severe, and there are impacts of catastrophic nature such as head to goal, or head to ground impacts that

could seriously injure an athlete. The addition of a head guard or helmet to the game of soccer for added protection is not a bad idea but finding a head guard that would provide ample protection in both minor and major situation is something that needs further consideration.

2. The Full 90™ head guards are being implemented to youth groups as a required piece of equipment for participation, the long term effects or benefits of wearing this head guard may be due further investigation.

Recommendations for Further Study

Future research and study might include the following concepts:

1. A comparison of head injury data for those individuals wearing this head guard or something of its nature, compared to that of a group's head injury rate while unprotected is an area of necessity.
2. The testing protocols used in this study are a good start in examining the performance characteristics of the Full 90™ Select head guard, yet more realistic parameters and procedures need to be done using model head forms and real life situations to accurately measure the true capabilities of this performance head guard.
3. This product did show signs of effectiveness but I would not recommend this protective device for soccer players in either youth or professional levels of soccer competition. Helmets are created and made to either sustain multiple impacts or one catastrophic impact. This head guard did show signs of being effective in multiple impact attenuation but it is not

recommended to wear this product in the hope that it may have some effectiveness,

4. It is recommended that testing takes place on future products to find a protective head guard or helmet that does offer significant protection for the situational hazards of the game of soccer.
5. There was a reduction of impact force found in this study, yet further study needs to be done to show if this reduction is biomechanically sufficient enough to create a decrease in injury prevalence.
6. Further study should be done in observing angular accelerations and the role these head guards play in reducing the angular accelerations ball impacts have on the head.

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APPENDIX

Table A1. Peak Impact Forces in N for Ball Drop Tests

Day 1	Control Impact Day 1	M. I. Peak Impacts Day 1	C.T.Peak Impacts Day 1
1	1268.64	1122.58	1075.96
2	1293.41	999.1	1012.22
3	1239.14	1096.36	1070.86
4		1107.64	1152.08
5		1063.57	934.27
6		1000.2	
7		1077.05	
8		1073.4	
9		1019.5	
10		1024.6	
11		1076.32	
12		1066.12	
13		1021.69	
14		1190.33	
15		973.97	

Day 2	Control Impact Day 2	M.I Peak Impacts Day 2	C.T. Peak Impacts Day 2
1	1295.51	1008.49	1113.75
2	1338.12	1277.3	1094.08
3	1340.31	1160.74	1114.12
4		1075.14	989.18
5		1103.38	1020.51
6		1042	
7		1129.05	
8		1046.73	
9		1239.42	
10		995.74	
11		1130.87	
12		1070.41	
13		991.01	
14		1154.91	

15		1117.03	
Day 3	**Control Impact Day 3**	**M.I Peak Impacts Day 3**	**C.T. Peak Impacts Day 3**
1	1223.21	1041.09	1158.01
2	1262.91	1055.3	1090.99
3	1220.66	1120.5	1168.94
4		970.43	1018.87
5		952.22	1083.34
6		1172.94	
7		984.63	
8		993.74	
9		1013.78	
10		1097.18	
11		1123.05	
12		1056.02	
13		1109.2	
14		1058.57	
15		1096.82	

Table A2. Calculated Impact Velocities in m/s.

Day 1 Calculated Impact velocities		
Control	**Multiple Impact**	**Wet Conditioned**
8.64	7.92	9
9	8.64	8.64
	8.64	
	8.64	

Day 2 Calculated Impact Velocities		
Control	**Multiple Impact**	**Wet Conditioned**
9.24	8.88	8.16
	8.52	8.52
	8.52	
	8.16	

Day 3 Calculated Impact Velocities		
Control	**Multiple Impact**	**Wet Conditioned**
8.64	8.16	9.6
	8.64	9
	9	
	8.52	

Table A3. Average Ball Impact Velocity.

	Control (m/s)	Multiple Impact (m/s)	Conditioned (m/s)
Day 1 Avg.	8.64	8.30	8.82
Day 2 Avg.	9.24	8.52	8.34
Day 3 Avg.	8.64	8.58	9.30
Total Avg.	8.84	8.47	8.82