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Effectiveness of a football over helmet padding system in reducing peak acceleration of the head and severity index 2014

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Effectiveness of a Football Over-Helmet Padding System
in Reducing Peak Acceleration of the Head and Severity Index

by

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ABSTRACT

The purpose of this study was to determine if: (a) a football helmet equipped with the Guardian Cap meets the National Operating Committee on Standards for Athletic Equipment (NOCSAE) football helmet standards and (b) if the Severity Indexes and peak accelerations produced during the NOCSAE impact tests were smaller for a football helmet equipped with the Guardian Cap over-helmet padding system than for the same helmet without the Guardian Cap. A total of 54 drop impact tests were completed, 27 on the football helmet alone and 27 on the football helmet equipped with the Guardian Cap. Tests were completed on seven different locations on the helmet at four different velocities and two different temperatures as per NOCSAE test standards. When the helmet was outfitted with the Guardian Cap, the highest Severity Index (SI) recorded was 751 at the rear impact location as compared to an SI of 842 at the same impact location on the helmet alone. Overall, the average SI when the Guardian Cap was attached was 324 ± 195 as compared to an overall average of 368 ± 219 for the helmet alone. The average peak acceleration (gmax) for the helmet with the Guardian Cap was 85 g's ± 23 as compared to 91 g's ± 26 for the helmet alone. These data for the Guardian Cap covered football helmet were below the maximum SI allowed by NOCSAE to be a certified football helmet. The SI and peak accelerations for the Guardian Cap covered football helmet were smaller than the SI and peak accelerations for the helmet alone on the NOCSAE impact tests. Medical professionals, coaches, players and parents can use this information to make informed decisions on the role of the Guardian Cap in possibly preventing or limiting the risk of concussions in football.

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CHAPTER 1

INTRODUCTION

Increased media attention on sports-related concussions has heightened the public's awareness of the risks associated with concussions, especially in American football. In 2013, the National Football League (NFL) reached a tentative settlement of $765 million with more than 4,000 former players who had sued the NFL for not revealing the long term dangers of concussions. Autopsies on a number of former NFL players revealed that many of them suffered from chronic traumatic encephalopathy (CTE), which is caused by repetitive brain injury including multiple concussions (McKee, et al., 2009). Football organizations are now searching for ways to reduce the incidence and severity of concussions. One approach is to change the rules such as limiting helmet to helmet hits and addressing criteria that must be met before a concussed athlete can be approved for return to play by a medical professional.

Another approach is to improve the athletes' protective equipment. Equipment improvements have been primarily directed towards reducing the magnitude impact forces to the head. Over-helmet padding systems have been developed in an effort to reduce concussions in football players. Over-helmet padding systems may have the ability to lessen the head impact forces encountered in football to values below the threshold of concussion. According to the 4th International Conference on Concussion in Sport Consensus Statement, helmets would need to decrease linear acceleration to below 50 g and decrease angular acceleration to below 1500 rad/s^2 to optimize their effectiveness against concussions (McCrory, et al., 2013). Over-helmet padding systems are relatively inexpensive and thus more widely accessible to football players at all levels of play. A measure of the effectiveness of over-helmet padding systems to reduce concussive forces would be valuable to medical professionals and the football community.

Statement of the Problem

Over-helmet padding systems have been developed to decrease the magnitude of potentially concussion causing head impact forces in American football. Several performance characteristics of one over-helmet padding system, the Guardian Cap, have been tested and reported, which include coefficient of friction tests (Bureau Veritas Consumer Products Services (Hong Kong) LTD, 2012), sunlight exposure tests (Advanced Technical Research, 2013) and various impact tests (Oregon Ballistic Laboratories, 2011; Sport Injury and Ballistic Biomechanics Group, 2011). The impact tests reported were similar, but not identical to, the impact tests specified by the National Operating Committee on Sports and Athletic Equipment (NOCSAE) for football helmets. The largest governing bodies for collegiate and high school football in the United States, the National Collegiate Athletics Association (NCAA) and the National Federation of State High School Associations (NFHS), both require football players to wear helmets that meet performance standards set by NOCSAE as described in *Standard Performance Specification for Newly Manufactured Football Helmets* (NOCSAE DOC (ND)002-11m12). Use of a football helmet equipped with a Guardian Cap is not currently allowed by the NCAA or NFHS since the helmet and Guardian Cap together have not been tested to determine if the helmet and cap system meet NOCSAE football helmet standards. Therefore, does a NOCSAE approved football helmet still meet NOCSAE standards when it is equipped with a Guardian Cap? If so, are the Severity Indexes and peak accelerations (gmax) produced during NOCSAE impact tests on a Guardian Cap equipped helmet, smaller than those measures for the helmet alone?

Purpose

The purpose of this study was to determine if a football helmet equipped with the Guardian Cap over-helmet padding system met the NOCSAE football helmet standard, NOCSAE DOC (ND)002-11m12. A secondary purpose was to determine if the Severity Indexes and peak accelerations produced during the NOCSAE impact tests were smaller for a football helmet equipped with the Guardian Cap over-helmet padding system than for the same helmet alone.

Hypotheses

The following hypotheses were proposed:

(1) A football helmet equipped with a Guardian Cap over-helmet padding system would the NOCSAE football helmet standard.

(2) The Guardian Cap equipped football helmet would reduce Severity Index and peak acceleration in the NOCSAE impact tests than the football helmet alone.

Delimitations

The study was delimited in the following ways:

(1) Only one football helmet was tested, a new, unused, youth size large Recruit Hybrid Schutt football helmet. This helmet size was selected because it fit the medium size NOCSAE headform for testing.

(2) The Guardian Cap tested was new and unused.

(3) Testing was completed on a headform and not on a human model. The headform was a medium size NOCSAE headform.

(4) Testing was completed in a laboratory setting and all testing was in compliance with NOCSAE test standards.

Limitations

The NOCSAE football helmet standard required that the faceguard be removed from the helmet before impact testing. The Guardian Cap, however, was designed to attach to the helmet with straps that wrap around the bars of the facemask and then snap onto them selves. For the current study, the facemask was removed from the helmet and the Guardian Cap was attached to the helmet by snapping the straps to a snap fastened between two layers of padding inside the helmet. These snaps may have affected the performance of the padding and thus affected the outcome of the impact test.

Assumptions

It was assumed that the test instruments at Intertek Laboratories (Cortland, NY) were all qualified and calibrated yearly as per NOCSAE standards. All Intertek technicians performing the tests were assumed to have sufficient training using and working with the NOCSAE testing equipment. At the time of testing, Intertek laboratories was accredited by the Standards Council of Canada (SCC), which was recognized by NOCSAE as an accredited laboratory for testing.

Definition of Terms (from NOCSAE standard ND 001-13m13)

NOCSAE	National Operating Committee on Standards for Athletic Equipment
Ambient Temperature	The normal temperature of the lab (72°F ± 5° or 22°C ± 2° C) according to NOCSAE test standards
Concussion	complex pathophysiological process affecting the brain, induced by biomechanical forces (McCrory, et al., 2013)
Headform	an instrumented model human head designed to fit the carriage assembly and possessing a high bio-fidelity
Headgear	any device placed on the head, or attached to any other appliance place on the head, to provide protection to the head and/or face of the wearer
Helmet	a protective device worn on the head in an effort to reduce or minimize injury to that portion of the head which is within the

	specified area of coverage while participating in various activities where risk of head injury is recognized
High Temperature	115° ± 5°F or 46° ± 3°C according to NOCSAE test standards
Impact Area	the area above the basic plane aft of a specified point anterior to the coronal plane and above the reference plane forward of that same point unless otherwise specified in an appropriate NOCSAE standard performance specification.
Modular Elastomer Programmer (MEP)	a cylindrical shaped pad used as the impact surface
Reference Plane	a plane marked on the headforms at a specified distance above and parallel to the basic plane
Severity Index (SI)	a measure of the severity of impact with respect to the instantaneous acceleration experienced by the headform as it is impacted. Acceptable SI levels measured during impact cannot exceed the limit specified in the individual standard performance specification:

The Severity Index is defined as:

$$SI = \int_0^T A^{2.5} dt$$

Where: *A* is the instantaneous resultant acceleration expressed as a multiple of *g* (acceleration of gravity); *dt* are the time increments in seconds; and the integration is carried out over the essential duration (*T*) of the acceleration pulse.

Triaxial Accelerometer	a small piezoelectric acceleration transducer with three axes, designed specifically for vibration measurement in three orthogonal axes. The accelerometer must be mounted at the center of gravity of the test headform with a sensitive axis aligned to within 5 degrees of the vertical when the headform is in the top impact position.

<u>*Impact Locations*</u>

Front (F)	located in the median plane approximately 1-in above the anterior intersection of the median and reference plane
Front Boss (FB)	a point approximately in the 45 degree plane from the median plane measured clockwise and located approximately above the reference plane
Side (S)	located approximately at the intersection of the reference and coronal planes on the right side of the headform

Rear Boss (RB)	a point approximately on the reference place located approximately 135 degrees clockwise from the anterior intersection of the median and reference plane
Rear (R)	approximately at the posterior intersection of the median and reference planes
Top (T)	located approximately at the intersection of the median and coronal planes.
Random	any individual impact location selected from any point within the impact area so that the initial point of contact between the headform and the impact surface shall be on or above the lines that define the impact area as specified in the appropriate NOCSAE performance specification.

Significance of the Study

Determining whether a football helmet equipped with the Guardian Cap over-helmet padding system meets the NOCSAE football helmet standards will provide football rule makers, as well as football coaches and players, more information about the value of using over-helmet padding systems to decrease the possible risk for concussions. This information can then help determine appropriate preventative measures for the future generations with regards to concussion in sports.

CHAPTER 2

REVIEW OF LITERATURE

The purpose of this study was to determine if the Guardian Cap over-helmet padding system met the NOCSAE standard for football helmets and if the Guardian Cap over-helmet padding system produced lower SI and peak accelerations during the NOCSAE impact tests than the helmet alone. If the Guardian Cap covered helmet did perform better on the NOCSAE test than the helmet alone, the Guardian may be used to decrease possible concussive impact forces in football. If these forces were decreased or eliminated, it may be possible to decrease the incidence of concussions in football.

Throughout this review of the literature, various topics relating to concussions are discussed. The areas discussed include: concussion causes, factors associated with concussion incidence; mechanics of head injuries and concussions; prevention of concussions; specific football helmet standards; and the Guardian Cap. All these topics relate to concussions and possible prevention of concussions, specifically in football.

Concussion Causes

Concussions can lead to debilitating effects, especially in those athletes who have not recovered properly. These long term and life threatening effects include second impact syndrome, chronic traumatic encephalopathy (CTE) and even death. Epidemiology studies suggest that there are estimated to be 1.6-3.8 million concussions per year in the United States with approximately 300,000 being sport related (Grady, 2010; Gessel, Fields, Collins, Dick & Comstock, 2007). Guskiewicz, Weaver, Padua and Garrett (2000) suggest that the motivation of the athlete to compete in a more competitive and aggressive fashion has led to bigger, stronger and faster athletes which can increase the forces associated with game play and, therefore, may increase the incidence of concussions. This motivation has made the issue of concussions in sport a more prevalent research topic in the current literature. A concussion can be defined in many different ways. According to the Fourth International Consensus Statement on Concussion in Sport, a concussion was defined as a "complex pathophysiological process affecting the brain, induced by biomechanical forces" (McCrory et al., 2013). These traumatic forces to the head can occur in a variety of fashions in athletic events. Some of these mechanisms include (Gessel, 2007):

- Contact with another person
- Contact with equipment
- Contact with playing surface

The most common mechanism for sustaining a concussion for high school athletes was contact with another player and, more specifically, head to head contact (Meehan, D'Hemecourt, & Comstock, 2010). One feature that may cause a concussion is a direct blow to the head, face, neck or elsewhere on the body which transmits an "impulsive" force to the head (McCrory et al., 2013).

Factors Associated with Concussion Incidence

Recent literature has looked at the factors that may be associated with concussion incidence in different populations. These factors include age or level of school, sex, sport played and number of previous concussions sustained in the past. Current literature suggests that there are differences between age or current level of play and concussion incidence. In an epidemiology study conducted by Guskiewicz, Weaver, Padua and Garrett in 2000 on collegiate and high school football players, the authors showed that the incidence of concussions were the highest at the high school level compared to any division collegiate level. In a more recent study conducted by Gessel, et al. (2007) on various sports across the high school and collegiate level, concussions represented 8.9% of all high school injuries and 5.8% of all collegiate injuries. Gessel, et al. (2007) also showed that collegiate athletes had a higher rate of concussion as a function of athletic exposures when compared to high school athletes despite concussions representing a higher proportion of injuries in high school athletes. Some explanations for the higher concussion rate in high school athletes include: the potential for more playing time, lower skill level and a lower quality of equipment (Gessel, et al., 2007).

When comparing concussions by sports, football and soccer have higher concussion rates than sports like wrestling and volleyball (Gessel, et al., 2007), which may be related to the nature of the sport. Football is an aggressive contact sport so injuries, including concussions, will be seen no matter what the circumstances are, as the collisions have increased and the players are becoming more aggressive (Guskiwicz, et al., 2000). Soccer may have a higher concussion rate due to the fact that players head the ball and in some cases they may miss and hit another player's head (Covassin et al., 2003).

Another identified factor that affects concussion incidence is the sex of the athlete. Research suggests that concussion rates are higher in females than males when compared to sports in which both sexes play. This trend is not only seen in high school athletes but in collegiate athletes as well (Gessel, et al., 2007). Covassin, Swanik and Sachs (2003) looked at specific collegiate teams and the differences between the sexes. They showed that over a three year period, females sustained more total concussions than their male counterparts while also having the highest concussion rate for game play. Possible explanations for females having a higher concussion rate than males include: females having weaker neck muscles and coaches and parents may be more protective of females which can lead to a higher report rate (Covassin et al., 2003; Gessel, et al., 2007). With more girls now playing youth football, their risk of concussion may dangerously high since concussion rates are high in football and higer in females than males.

Another important factor that may affect concussion incidence is the athlete's previous history of concussions (Guskiewicz, et al., 2003; Delaney, Lacroix, Lederc & Johnston, 2002). Over the course of a three year study, Guskiewicz and associates followed collegiate football players over the course of their playing career or until the study was over in 2001. The researchers kept track of concussions and number of repeat concussions during the football seasons. Results of the study showed that football players with three or more concussions were three times more likely to sustain another concussion then those players who had no history of concussion (Guskiewicz, et al., 2003).

Mechanics of Head Injuries and Concussions

Concussions, as well as head injuries in general, may be influenced by the forces transmitted through the neck when the head is impacted. In 2007, Viano, Casson, and Pellman reported the biomechanics of a football player when he was struck by another football player as part of a study that looked at concussions in professional football. As stated previously, weaker neck muscles can be a cause of increased concussions in females and younger populations. Vaino et al. (2007) suggested a correlation between the displacement of the head and neck and concussions relating to neck musculature. This correlation starts at initial impact, where there are lateral accelerations and rotational accelerations which bend the neck. After initial contact, lateral and rotational velocity is caused by the head acceleration at impact which displaces the head further. This displacement and rotation load the neck with potential energy and forces the head and neck to move to the right or left depending on where the initial hit occurred, which also builds up lateral shear force and axial neck tension. Put more simply, there are forces that build up within the neck when it moves which may cause other forces to increase. The forces and accelerations in the neck result in further deformation of the head and neck (Viano, Casson. & Pellman, 2007). This difference in head displacement between initial contact and final outcome can be influenced by the strength and stability of the neck musculature. Vaino et al. propose that the weak neck musculature of females and younger populations could be a reason why there are more concussions in those populations and why they can sustain a concussion from less severe impacts then those of their older male counterparts (Viano et al., 2007).

The acceleration components also play a part in the incidence of concussions. Essentially, there are two kinds of accelerations that account for most of the concussions in sports, linear and rotational. Some studies suggest that linear acceleration alone produces little motion of the brain while rotational acceleration correlates the highest with average peak brain deformations and diffuse brain injuries (Institute of Medicine [IOM] and National Research Council [NRC], 2014).

Concussion Prevention Techniques and Equipment

Factors that are vital to preventing concussions include: training the athletes of proper techniques, fitting and wearing equipment properly and increasing awareness of concussions (Guskiewicz et al., 2000). By being aware of concussions and recognizing the signs and symptoms, we are able to develop proper policies and procedures in concussion prevention.

Proper equipment fitting plays a vital role in prevention, especially in football. Improperly fitted equipment may not provide the protection necessary to aid in preventing or limiting the severity of a concussion. Some protective equipment utilized in football include helmets and mouthguards. Standard specifications for football helmet performance have been developed by several different organizations including the National Operating Committee on

Standards for Athletic Equipment (NOCSAE) and the American Society for Testing and Materials International (ASTMI).

The use of helmets in football has been demonstrated to decrease the rate of traumatic head injuries sustained in athletics (McCrory et al., 2009; Heck, Clarke, Peterson, Torg, & Weis, 2004). Helmets are used to increase the surface area where the impact force is applied which decreases the pressure that is transmitted to the head (Barth, Freeman, Broshek, & Varney, 2001). A helmet is designed to alter the energy transfer of an impact to the head, which in turn may reduce the acceleration the head experiences (Rowson, et al., 2014). This acceleration and resulting displacement of the head have been shown to be related to concussions (Rowson, et al., 2014; Viano, et al., 2007). For this reason, the fit of the helmet is one of the most crucial elements to a helmet's protection strategy. Inside the helmet, there are cushions which increase the displacement of the helmet shell and liner. This increased displacement reduces the forces transmitted to the head and may thus reduce the risk of head injury (Barth et al., 2001).

The role of helmets in decreasing concussion incidence has come into question, even though it has been shown that helmets do reduce impact forces to the brain (McCrory, et al., 2013). Rowson et al. (2014) recently completed a study on different designs of football helmets. They found that athletes wearing the Riddell Revolution helmet had a lower incidence of concussion than the players wearing the Riddell VSR4 helmet (Rowson et al., 2014). Helmets differ in their ability to reduce the acceleration of the head in an impact.

Mouthguards are another piece of protective equipment that, if fitted properly, can lessen the severity of an impact force and prevent dental and facial injuries (McCrory et al., 2009; Barth et al., 2001; Daneshvar et al., 2011). If an athlete gets hit in the mouth, the mouthguard will act as a shock absorber between the mandible and the maxilla to decrease the force that is being sent to the brain. The mouthguard increases the time and distance of the impact force, reducing the magnitude of the impact force, and thus offering the brain some protection injury (Barth et al., 2001; Winters, 2001). This may not completely prevent the athlete from sustaining an injury such as a concussion, however (Winters, 2001; McCrory, et al., 2013).

Generally, there are three different kinds of mouthguards: stock, boil and bite and custom. Each type of mouthguard has different properties that can help diminish the force from a hit to the face. The fitting of a mouthguard plays an important role in comfort and protection. The more snug a mouthguard fits to the teeth, the more comfortable and effective it will be for the athlete (Winters, 2001). If the athlete is more comfortable with the fit of the mouthguard, the athlete may be less likely to alter or not wear the mouthguard.

Proper technique and adherence to the rules of the game must be stressed to the athletes as a prevention strategy (Kissick & Johnston, 2005). In football, the use of the helmet as a tool to make a tackle is illegal. By using headgear as a weapon, the player places unnecessary axial loads on his cervical spine which can cause traumatic injuries such as cervical spine fractures and dislocations (Heck et al., 2004). Tegner and Lorentzon (1991) suggest that in hockey 39.4% of all injuries occur to the head and face. They suggest stricter enforcement of the rules to help prevent these injuries (Tegner & Lorentzon, 1991). This type of enforcement should be translated to football where, as mentioned earlier, using the helmet as a weapon is illegal.

Along with proper protective equipment and adherence to the rules of the game, comes the concept of risk compensation. This concept of risk compensation looks at the athletes' behavioral changes when they use protective equipment (McCrory, et al., 2013). Studies done on rugby players suggested that if a player wears headgear, he/she may perceive the impact force to be softer than it actually is. This also applies to tackling, for when the player is wearing headgear he/she believes that they can hit harder because they perceive that the hit will be lessened by the headgear (McIntosh, 2005). Protective equipment is utilized to help prevent injuries, but at the same time this type of behavior may increase the incidence of various injuries (McCrory et al. 2013). This can relates to football where tackling and hitting the opponent hard can be a main factor of the sport.

Football Helmet Standards

The National Operating Committee on Standards for Athletic Equipment (NOCSAE) was established in 1969 to research injury reduction techniques in athletics (NOCSAE, 2011). In the early 1970's, NOCSAE started to develop and implement standards in many sports, beginning with football (Gwin, Chu, Diamond, Halstead, Crisco & Greenwald, 2010). Before the NOCSAE football helmet standard was released in 1978, the highest incidence of fatalities in football due to head and cervical spine injuries was recorded between 1965 and 1974 (Mueller, 1998). The National Collegiate Athletic Association (NCAA) adopted NOCSAE's football helmet standards for the 1978 football season and in 1980, the National Federation of State High School Associations (NFHS) also adopted the NOCSAE football helmet standard. Between the years of 1975 and 1984, a distinct decrease in head and cervical spine injuries occurred (Mueller, 1998).

NOCSAE now has standards for helmets for several other sports besides football. Each NOCSAE helmet standard specifies different criteria for the peak accelerations and Severity Indexes (SI) that headform covered by a helmet can experience during an impact test.. For a newly manufactured football helmet, the NOCSAE football helmet standard specifies that the peak Severity Index for any impact should not exceed 1200 SI and the impacts at the lowest velocity should not exceed 300 SI (NOCSAE, 2012). Once a football helmet has been certified to meet the NOCSAE standard, the helmet must undergo reconditioning each year for the helmet to remain in use.

The NOCSAE football helmet standard specifies drop tests that cause impact to occur at specific locations on the helmet. These drop tests occur while the helmet is placed on a NOCSAE standardized headform. Inside the headform is a triaxial accelerometer which measures acceleration along the antero-posterior, inferior-superior and medial-lateral axes. The accelerometer measures the linear acceleration of the center of gravity of the headform during impact of a drop test. From the acceleration data, the peak acceleration and the Severity Index of each impact is computed. The Severity Index is computed from the acceleration signal during the period of peak acceleration (measured in g's) of the impact and the duration of the period of peak acceleration (measured in seconds) ((NOCSAE), 2013).

The NOCSAE standards that apply to newly manufactured football helmets are the *Standard test method and equipment used in evaluating the performance characteristics or protective headgear/equipment* (ND001-11m13) and the *Standard performance specification for newly manufactured football helmets* (ND002-11m12). Both of these standards require that the face guard be removed from the football helmet before the helmet is tested. NOCSAE has also published standards for other football equipment including football players' gloves (ND019-10m13) and football facemasks (ND087-11m11, ND087-12m12).

Besides NOCSAE, the American Society for Testing and Materials International (ASTMI) has also developed a standard for football helmets, *Standard Test Method for Shock-Attenuation Characteristics of Protective Headgear for Football* (ASTM F429 – 10). In the ASTMI standard, the football helmet is attached to a metal headform with a built in linear accelerometer and then dropped onto an impact surface. The helmet is tested on six different locations in various conditions such as ambient temperature, high/low temperature and after immersed in water and the linear acceleration of the headform is measured during impact. The criterion measure for the ASTMI football helmet standard is the peak acceleration (gmax) expressed as multiples of the acceleration due to gravity. According to the ASTMI standard for football helmets, the average gmax of three tests to the six locations should not exceed 275 g. For the two test sites with the highest gmax, no single impact should be over 300 g (ASTMI, 2010).

Over-Helmet Padding Systems

The Guardian Cap is an example of a football over-helmet padding system which was developed to reduce head acceleration and increase the time of impact (Guardian Caps, 2013). Over-helmet padding systems decrease the forces athletes experience during impacts to the head by dampening and redistributing the energy of the impact (Guardian Caps, 2013). This padding system is a soft outer shell of padding that goes over the helmet. The Guardian Cap attaches by four straps to the facemask and one Velcro strap to the back of the helmet (Guardian Caps, 2013).

The Guardian Cap was impact tested at Wayne State University and and reported by Andrecovich (2011). Three impact conditions were examined: helmet to helmet impacts, helmet with Guardian Cap to helmet impacts, and helmet with Guardian Cap to helmet with Guardian Cap impacts (Andrecovich, 2011). The impacts occurred when a trolley with a helmeted headform mounted to it collided with a fixed helmeted headform. The helmets or helmets with Guardian Caps were mounted to the headforms. Two impact velocities were tested. The impacts of the Guardian Cap covered helmet with another Guardian Cap covered helmet had the lowest

Severity Indexes (SI), head injury criteria (HIC) and peak linear accelerations (PLA) of the three impact conditions for both velocities.

Other impact tests on the Guardian were conducted by Oregon Ballistic Laboratories (2011). These impact tests used a linear impactor to strike a helmeted headform or Guardian Cap covered helmeted headform. Three different impact sites were tested. HIC and peak acceleration were reported. The results were similar those reported by Andrecovich (2011), with smaller accelerations and head injury criteria for the Guardian Cap covered helmet than for the helmet alone (Oregon Ballistic Laboratories, 2011).

Another over-helmet padding system, the ProCap, was developed in 1989 by Bert Straus. The ProCap was a half-inch thick urethane foam mold that was worn over the top of football helmets (Helyar, 2013). In the 1990's, the ProCap was worn by numerous football athletes including professional football players Mark Kelso from the Buffalo Bills and Mark Wallace from the San Francisco 49er's (Helyar, 2013). The developer of the ProCap impact tested his invention at Wayne State University and saw a decrease in impact forces by 30% (Helyar, 2013). Bert Straus decided to present his findings to the NFL brain injury committee and this committee essentially derailed further production. After numerous meetings with this committee, Straus re-developed the ProCap into a newer model called the Gladiator. In August 2011, funding for the ProCap and Gladiator ran out and the development and production of these over-helmet padding systems ceased (Helyar, 2013).

Summary

Current literature has led to a better understanding of concussions and helped develop treatments, policies and prevention guidelines. Concussions in football are occurring at an exceeding rate, often with debilitating outcomes to players and there remain many questions to be answered about concussions, return to play guidelines and their correlation to different aspects of the athlete.

In conjunction with the knowledge of concussion causes, factors associated with concussion incidence, mechanics of head injuries, prevention strategies and various standards set in place, future research and standards can be made for protective headgear worn in sports. Over-helmet padding systems can incorporate this body of knowledge and possibly become the technology that athletes will be wearing in the future. However, there is limited knowledge on whether or not these systems meet NOCSAE standards. As mentioned previously, during ProCap impact testing, there was a 30% decrease in impact forces (Helyar, 2013). Results of the ProCap testing indicate that over-helmet padding systems can reduce impact force, but these over-helmet padding systems are not yet approved by NOCSAE.

CHAPTER 3

METHODS

Stronger, bigger and faster athletes in contact sports such as football create larger impact forces when players collide with one another or with the sporting equipment or the environment in which they are playing. These increased impact forces will lead to more injuries, including concussions. Football over-helmet padding systems may reduce the head impact forces associated with collisions in football. By reducing these impact forces, the over-helmet padding system can be a step towards the prevention of concussions in football. The purpose of this study was to determine if the Guardian Cap over-helmet padding system met the NOCSAE standard for football helmets and if the Guardian Cap over-helmet padding system produced lower SI and peak accelerations during the NOCSAE impact tests than the helmet alone.

Equipment

The football helmet used in all tests was a youth size large Recruit Hybrid Schutt helmet. This helmet fit a head size of 7⅛ - 7¼. This size helmet was chosen since it fit the medium size NOCSAE headform (size 7¼). The medium size NOCSAE headform was used in all the impact tests.

The Guardian Cap used in the tests was purchased directly from the manufacturer's website (www.guardiancaps.com/store/). The Guardian Cap is manufactured in only one size, however it is available in several colors. A silver colored cap was purchased and used in the tests. The Guardian Cap weighs less than 7 ounces. The inner padding is made of closed-cell, modified EVA foam while the outside material is a lycra-spandex blend. Figure 1 shows the Guardian Cap placed on the Schutt football helmet.

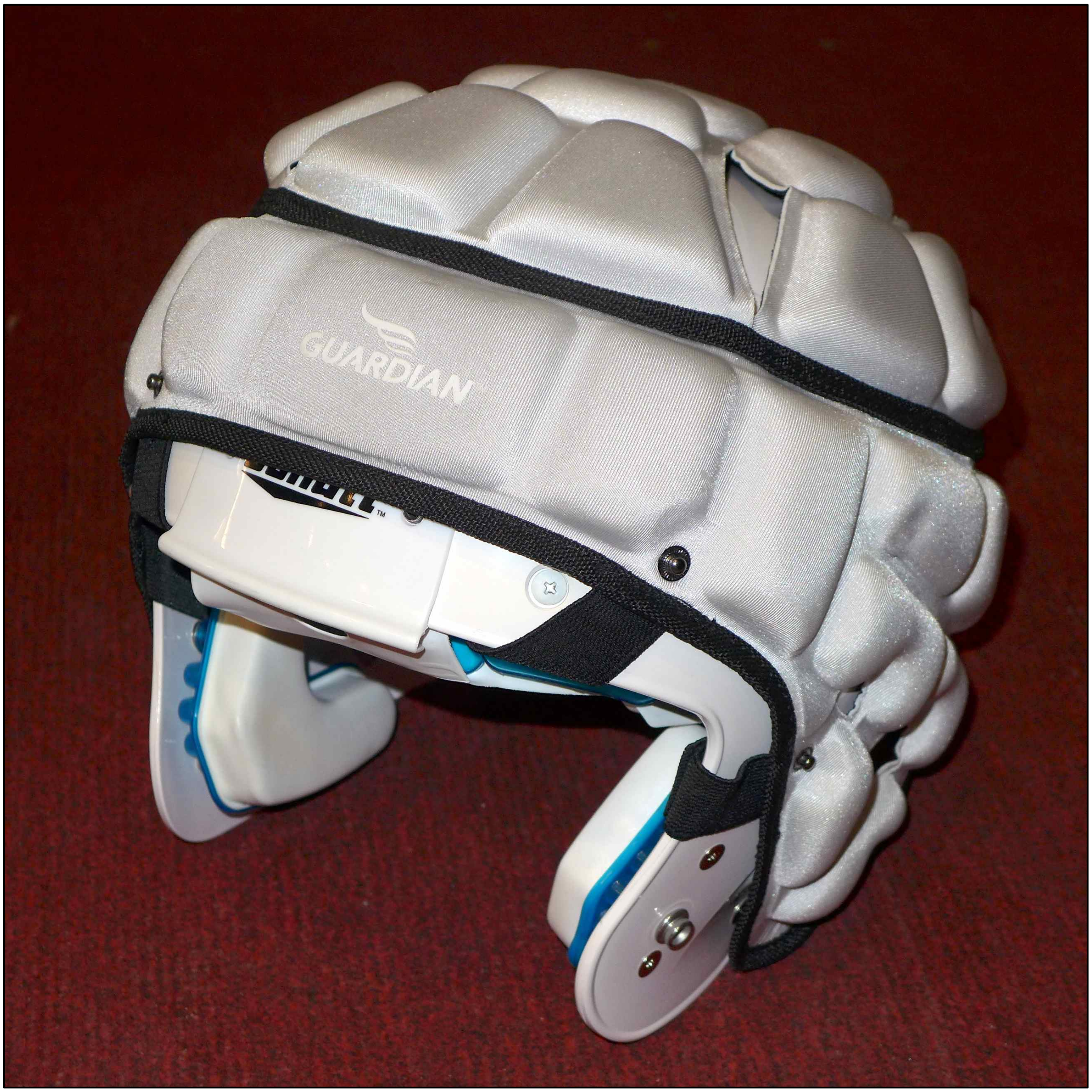

Figure 1. Guardian Cap attached to Schutt football helmet.

The NOCSAE headforms are biofidelic headforms that come in three sizes: small, medium, and large. Full description and specifications of the NOCSAE headforms is found in *Standard test method and equipment used in evaluating the performance characteristics of* *protective headgear/equipment* (NOCSAE DOC (ND) 001- 11m13). A medium size NOCSAE headform was used for all impact tests.

The helmet impact testing equipment used was located at Intertek Laboratories in Cortland, New York. The basic components of the helmet impact testing equipment included:

- a wire guided drop carriage assembly onto which the NOCSAE headform was mounted and positioned;
- an anvil and anvil baseplate;
- a 3 inch thick MEP calibration pad and a 0.5 inch MEP testing pad which were mounted on the anvil for calibration and testing respectively;
- a triaxial accelerometer mounted in the NOCSAE headform;
- a data conditioner which sampled and analyzed the accelerometer data and calculated SI and peak acceleration;
- and various pieces of hardware to mount and adjust the equipment.

A picture of an assembled NOCSAE drop testing apparatus is shown in Figure 2. Full description and specifications of the drop testing equipment is found in *Standard test method and equipment used in evaluating the performance characteristics of protective headgear/equipment* (NOCSAE DOC (ND) 001- 11m13). This NOCSAE document also includes a list of the drop testing equipment components and vendors.

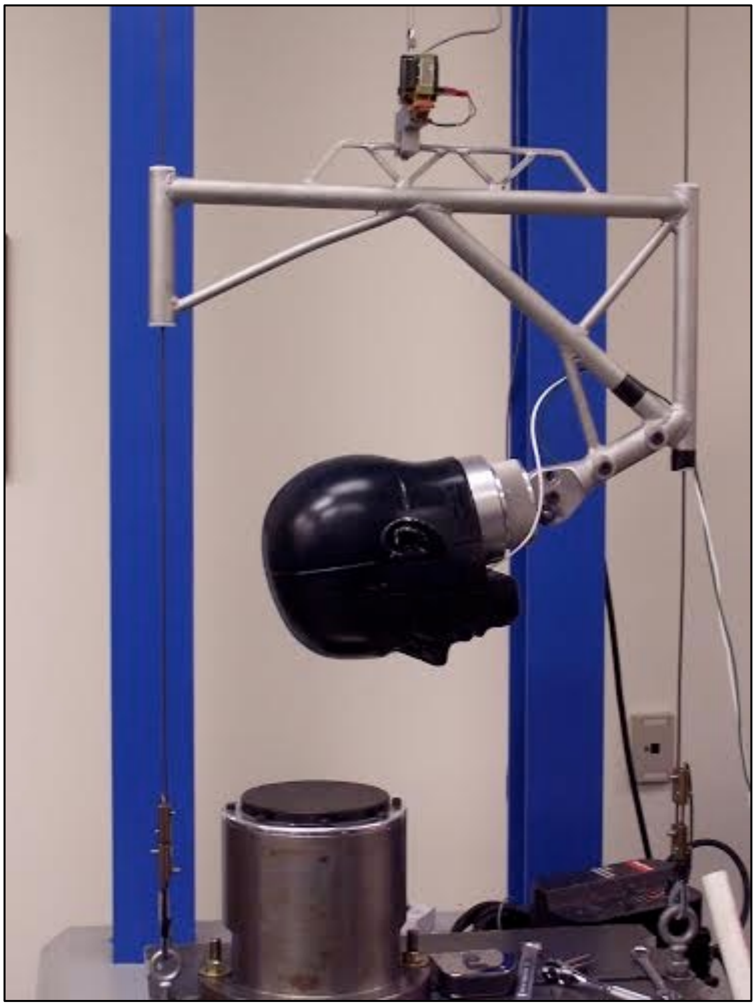

Figure 2. Drop test apparatus.

Impact Testing Procedures

The impact testing was completed at Intertek Laboratories in Cortland, New York. Intertek is accredited by the Standards Council of Canada (SCC) which is recognized by NOCSAE as an approved testing facility. The 27 impact tests described in the NOCSAE football helmet standard were conducted first on the Schutt football helmet covered with the Guardian Cap over-helmet padding system and then on the Schutt football helmet alone. The 27 impacts tests, as specified by the NOCSAE football helmet standard, included:

- four different impact velocity ranges (3.46-3.56 m/s, 4.23-4.36 m/s, 4.88-5.03 m/s, and 5.46-5.62 m/s)
- seven different impact locations (front, side, front boss, rear boss, rear, top, and a random location chosen by the test technician)
- and two different temperatures (ambient temperature (72°F ± 5°F) and high temperature (115°F ± 5°F)).

Not all impact velocity, location, and temperature combinations were tested, however. NOCSAE standard (ND) 002-11m12 shows the 27 NOCSAE specified combinations of impact velocity, impact location, and impact temperature that were tested.

The height of the drop carriage assembly was adjusted to achieve impact velocities within the four different velocity ranges specified by NOCSAE. The drop velocities were measured in the last 1.5 in (40 mm) of free fall before impact to confirm that the impact velocity was within the desired range for each impact test.

The laboratory temperature was maintained within the temperature range for the ambient temperature test condition. The laboratory temperature was monitored during testing. For the two high temperature impact tests, the helmet or the Guardian Cap covered helmet was conditioned at the high temperature for a minimum of four hours and a maximum of 24 hours prior to impact testing. The first impact test on the helmet or Guardian Cap covered helmet occurred between the first and second minute after removing the helmet or Guardian Cap covered helmet from the high temperature environment. The second high temperature impact test was then completed within 75 ± 15 seconds of the first impact test as specified by NOCSAE.

The impact locations on the helmet or Guardian Cap covered helmet were the front, right side, right front boss, right side boss, rear, top and a random location selected by the test technician. These are the impact locations specified by NOCSAE. The random impact location selected was the left side. These impact locations can be found in NOCSAE standard (ND) 001-

13m13. To produce impacts at the specified locations, the headform position and orientation on the drop carriage assembly was adjusted.

As per NOCSAE, a pretest system calibration check was performed prior to impact testing the helmet and prior to impact testing the helmet with the over-helmet padding system. To prepare the Schutt football helmet for testing, the face mask was removed from the helmet. After the system was calibrated, impact tests of the Guardian Cap covered helmet began. The 25 ambient temperature impact tests were completed ending with the slower impact velocity tests and ending with the faster impact velocity tests. Following the 25 ambient temperature impact tests of the Guardian Cap covered helmet, the 25 ambient impact tests of the helmet alone were completed. The high temperature impact tests on the Guardian Cap covered helmet were then completed followed by the high temperature impact tests on the helmet alone.

A typical impact test began by securing the helmet to the NOCSAE headform with the ear holes of the helmet lined up with the ear holes of the headform. For an impact test of the Guardian Cap covered helmet, the Guardian Cap was first attached to the helmet. The Guardian Cap is designed to be attached to a helmet by wrapping straps from the Guardian cap around the face guard. Snap fasteners are then used to connect each strap back to itself. Since the face guard was removed from the helmet, snap fasteners were attached to the interior surface of the helmet shell and the straps on the Guardian Cap were snapped to the interior surface of the helmet. After the helmet or the Guardian Cap covered helmet was secured to the headform, the headform was then secured to the drop carriage assembly and positioned so that the specified test location on the helmet impacted the test MEP pad. After positioning the headform, the drop carriage assembly with the helmeted headform attached was raised to the height that would produce the desired impact velocity. The drop carriage assembly was triggered to drop and the impact location on the helmet collided with the MEP test pad. The drop velocity of the lowest point on the helmet or Guardian Cap covered helmet was measured in the last 1.5 in (40 mm) of free fall prior to impact to confirm that the impact velocity was within the desired range for each impact test. If the drop velocity was not within the desired range, the drop height was adjusted and the test repeated.

Instantaneous acceleration of the headform was measured by the triaxial accelerometer mounted in the headform. The maximum Severity Index and peak acceleration were computed from the acceleration data. The SI and peak acceleration values were then recorded by the test technician. This procedure was completed for all 27 combinations of test locations, drop velocities and temperatures. After each helmet testing session, another system check was conducted as per NOCSAE standards. After completion of all the impact tests, the test technical completed a test report which included the SI and peak accelerations for each individual impact test. One report was completed for the Schutt football helmet alone and one report was completed for the Guardian Cap covered Schutt football helmet. These reports are included in the appendix.

Data Analysis

Measurements collected for each impact test included the Severity Index (SI) and the peak acceleration. A total of 54 SI's and 54 peak accelerations were measured, 27 for the helmet alone and 27 for the Guardian Cap equipped helmet. The performance of the helmet alone versus the Guardian Cap equipped helmet were compared by computing the differences between the SI's and peak accelerations for each of the 27 tests. Smaller SI's and smaller peak accelerations indicated better performance. The average and standard deviation of SI and peak acceleration were computed for each velocity range at ambient temperature and for each impact location.

CHAPTER 4

RESULTS AND DISCUSSION

The purpose of this study was to determine if a football helmet equipped with the Guardian Cap met NOCSAE standards and if the Guardian Cap over-helmet padding system produced lower SI and peak accelerations during the NOCSAE impact tests than the helmet alone.. Twenty-seven impact tests were completed for each helmet condition. The Severity Indexes and peak accelerations were measured reported for each impact test.

Results

Guardian Cap vs. NOCSAE standards. Descriptive statistics of the Severity Index and peak acceleration were computed for all impact tests for the 7 drop locations and velocities when the Guardian Cap was attached to the NOCSAE approved helmet for both Severity Index and peak acceleration. The location with the highest average SI when the Guardian Cap was attached was the rear location (*M*= 544, *SD*=339), followed by rear boss (*M*= 388, *SD*=243), top (*M*= 383, *SD*= 190), side (*M*= 345, *SD*=151), random location (left side) (*M*=279, *SD*=187), front boss (*M*=211, *SD*=132), and front (*M*=187,*SD*= 66). The actual Severity Indexes for every test site and velocity are listed in Table 3. The location with the highest average peak acceleration was the rear location (*M*=100 g, *SD*= 32g), followed by side (*M*=95 g,*SD*=21 g), top (*M*=90 g,*SD*=24 g), rear boss (*M*=88 g,*SD*= 28 g), random location (left side) (*M*= 85 g,*SD*= 30 g), front boss (*M*=73 g,*SD*= 22 g), and front (*M*= 66 g,*SD*= 7 g). All peak accelerations for all test sites and velocities are listed in table 4.

Table 1 Severity Indexes by Drop Location and Velocity for Helmet with Guardian Cap

Temperature	Velocity Range (m/s)	Front	Side	Front Boss	Rear Boss	Rear	Top	Random	Average	SD
Ambient	3.46-3.56	109	91	59	108	152	163	63	106	40
Ambient	4.23-4.36	139	195						167	40
Ambient	4.88-5.03	177	314						246	97
Ambient	5.46-5.62	259	455	287	530	751	498	397	454	166
Ambient	5.46-5.62	249	457	287	527	728	487	377	445	162
High	5.46-5.62		426						426	0
High	5.46-5.62		476						476	0
	Average	187	345	211	388	544	383	279		
	SD	66	151	132	243	339	190	187		
								Overall Average	324	
								Overall SD	195	

Table 2. Peak Accelerations by Drop Location and Velocity for Helmet with Guardian Cap

Temperature	Velocity Range (m/s)	Front	Side	Front Boss	Rear Boss	Rear	Top	Random	Average	SD
Ambient	3.46-3.56	61	58	48	56	63	63	50	57	6
Ambient	4.23-4.36	62	75						69	9
Ambient	4.88-5.03	60	92						76	23
Ambient	5.46-5.62	75	110	86	105	120	107	103	101	15
Ambient	5.46-5.62	73	111	86	104	118	100	101	99	15
High	5.46-5.62		104						104	0
High	5.46-5.62		113						113	0
	Average	66	95	73	88	100	90	85		
	SD	7	21	22	28	32	24	30		
								Overall Average	85	
								Overall SD	23	

Note. All accelerations are measured in multiples of g which is equal to 9.81 m/s^2

A helmet meets the NOCSAE football helmet standard if the SI for each of the 27 impact tests does not exceed 1200 and if the SI for each of the seven slow velocity (3.46 m/s) impact tests does not exceed 300. The Guardian Cap attached to a Schutt football helmet did meet the NOCSAE standard for newly manufactured football helmets ((ND) 002-11m12).

Guardian Cap vs. Helmet Alone. Descriptive statistics of the Severity Index and peak acceleration were computed for both test conditions, the Schutt football helmet alone and the Guardian Cap covered Schutt football helmet. The SI's for the impact tests of the helmet alone are shown in Table 5. The single maximum SI for the football helmet alone was 842 in the velocity range of 5.46 m/s - 5.62 m/s at the rear location whereas the single maximum SI for the when the football helmet was attached to the Guardian Cap was 751 at the same velocity range and location. The overall average SI was smaller for impact tests of the Guardian Cap covered football helmet (*M*=324, *SD*=195) than for impact tests of the football helmet alone (*M*=386, *SD*=219).

The same trend was seen across peak accelerations. The peak accelerations for the impact tests of the helmet alone are shown in table 6. The maximum peak acceleration for the football helmet alone was 135 g's for the impact test at the 5.46-5.62 m/s velocity range at the rear location while the maximum peak acceleration for the football helmet with the Guardian Cap was 120 g's for the impact test at the 5.46-5.62 m/s velocity range at the rear location. Overall, peak accelerations were smaller for the Guardian Cap covered helmet (*M*= 85 g's, *SD*= 23 g's) than for the helmet alone (*M*= 87 g's, *SD*= 26 g's).

Table 3. Severity Indexes by Drop Location and Velocity for Helmet Alone

Temperature	Velocity Range (m/s)	Front	Side	Front Boss	Rear Boss	Rear	Top	Random	Average	SD
Ambient	3.46-3.56	71	96	51	146	216	170	95	121	59
Ambient	4.23-4.36	121	203						162	58
Ambient	4.88-5.03	253	330						292	54
Ambient	5.46-5.62	298	508	359	612	842	521	463	515	178
Ambient	5.46-5.62	304	501	365	576	829	514	465	508	169
High	5.46-5.62		486						486	0
High	5.46-5.62		537						537	0
	Average	209	380	258	445	629	402	341	377	
	SD	107	174	180	259	358	201	213		
								Overall Average	368	
								Overall SD	219	

Table 4. Peak Accelerations by Drop Location and Velocity for Helmet Alone

Temperature	Velocity Range (m/s)	Front	Side	Front Boss	Rear Boss	Rear	Top	Random	Average	SD
Ambient	3.46-3.56	55	56	45	57	72	78	55	60	11
Ambient	4.23-4.36	54	77						66	16
Ambient	4.88-5.03	78	95						87	12
Ambient	5.46-5.62	82	120	102	110	135	99	110	108	17
Ambient	5.46-5.62	78	115	103	109	130	95	116	107	17
High	5.46-5.62		114						114	0
High	5.46-5.62		121						121	0
	Average	69	100	83	92	112	91	94		
	SD	14	25	33	30	35	11	34		
								Overall Average	91	
								Overall SD	26	

Note. All accelerations are measured in multiples of g which is equal to 9.81 m/s^2

Figure 7 shows the percent changes in SI for all impact tests between the Schutt football helmet alone and the Guardian Cap covered helmet. The Guardian Cap covered helmet reduced the SI in 24 of the 27 tests. The only three impact tests in which the helmet alone performed better based on SI were two ambient temperature impacts at the front of the helmet done at the 3.46-3.56 m/s velocity range and at the 4.23-4.36 m/s velocity range and the ambient temperature single impact at the right front boss at the 3.46-3.56 m/s velocity range. These were the two slowest impact velocity ranges. Across all 27 impacts, the Guardian Cap covered helmet reduced the SI by an average of 10% over the helmet alone.

Figure 8 shows the percent changes in peak acceleration for all impact tests between the Schutt football helmet alone and the Guardian Cap covered helmet. The Guardian Cap covered helmet reduced the peak acceleration in 23 of the 27 tests. The only four impact tests in which the helmet alone performed better based on peak acceleration were the two ambient temperature impacts at the front of the helmet done at the 3.46-3.56 m/s velocity range and 4.23-4.36 m/s velocity ranges, and the single ambient temperature impacts at the right side of the helmet and the right front boss both done at the 3.46-3.56 m/s velocity range. Across all 27 impacts, the Guardian Cap covered helmet reduced the peak acceleration by an average of 5% over the helmet alone.

Table 5. Percent Change in Severity Indexes between Helmet Alone and Helmet with Guardian Cap

Temperature	Velocity Range (m/s)	Front	Side	Front Boss	Rear Boss	Rear	Top	Random	Average	SD
Ambient	3.46-3.56	54%	-5%	16%	-26%	-30%	-4%	-34%	-4%	31%
Ambient	4.23-4.36	15%	-4%						5%	13%
Ambient	4.88-5.03	-30%	-5%						-17%	18%
Ambient	5.46-5.62	-13%	-10%	-20%	-13%	-11%	-4%	-14%	-12%	5%
Ambient	5.46-5.62	-18%	-9%	-21%	-9%	-12%	-5%	-19%	-13%	6%
High	5.46-5.62		-12%						-12%	0%
High	5.46-5.62		-11%						-11%	0%
	Average	1%	-8%	-9%	-16%	-18%	-5%	-22%		
	SD	33%	3%	21%	9%	10%	1%	10%		
								Overall Average	-10%	
								Overall SD	17%	

Table 6. Percent Change in Peak Accelerations between Helmet Alone and Helmet with Guardian Cap

Temperature	Velocity Range (m/s)	Front	Side	Front Boss	Rear Boss	Rear	Top	Random	Average	SD
Ambient	3.46-3.56	11%	4%	7%	-2%	-13%	-19%	-9%	-3%	11%
Ambient	4.23-4.36	15%	-3%						6%	12%
Ambient	4.88-5.03	-23%	-3%						-13%	14%
Ambient	5.46-5.62	-9%	-8%	-16%	-5%	-11%	8%	-6%	-7%	7%
Ambient	5.46-5.62	-6%	-3%	-17%	-5%	-9%	5%	-13%	-7%	7%
High	5.46-5.62		-9%						-9%	0%
High	5.46-5.62		-7%						-7%	0%
	Average	-2%	-4%	-9%	-4%	-11%	-2%	-9%		
	SD	15%	4%	13%	2%	2%	15%	3%		
								Overall Average	-5%	
								Overall SD	9%	

Note. All accelerations are measured in multiples of g which is equal to 9.81 m/s^2

Discussion

The helmet outfitted with the Guardian Cap reduced both the Severity Indexes and peak accelerations on the NOCSAE impact tests than the helmet alone. These results are similar to the results reported by Andrecovich (2011) with a different impact testing procedure. These impact tests involved two headforms, one attached to a trolley system and one that was stationary. The helmeted headform on the trolley collided with the stationary helmeted headform. Three different impact situations were tested: helmet to helmet, helmet to Guardian Cap covered helmet, and Guardian Cap covered helmet to Guardian Cap covered helmet. The results showed that the Guardian Cap equipped helmet reduced average Head Injury Criteria (HIC), average SI and average peak linear acceleration compared to helmet conditions without the Guardian Cap (Sport Injury and Ballistic Biomechanics Group, 2011). In the current study, the SI and peak accelerations produced during impact testing of the Guardian Cap covered NOCSAE approved helmet were smaller than these measures for the helmet alone. This was particularly the case for higher impact velocities where the potential for concussions is greater (up to 23% difference at the highest velocity). Overall, the average peak acceleration were smaller by 5% when the helmet was outfitted with the Guardian Cap compared to the helmet alone. Similarly, the SI was smaller by 10% on average (up to 30% at the highest velocity) when the Guardian Cap was worn over the helmet compared to the helmet alone. The results of the current study and the Sport Injury and Ballistic Biomechanics Group tests, suggest that the Guardian Cap can be an effective means to decrease potentially injury causing head impact forces as measured by SI and peak acceleration. Rowsen et. al (2014) and Viano et. al (2007) concluded that acceleration and the resulting displacement of the head upon impact were related to concussions. In the current study, the Guardian Cap covered helmed produced peak accelerations thatwere 5% smaller on average and up to 17% smaller at the highest velocity that the peak accelerations observed for the helmet alone.

CHAPTER 5

CONCLUSION, APPLICATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The purpose of this study was to determine if a football helmet equipped with the Guardian Cap met NOCSAE football helmet standard and if the Guardian Cap equipped helmet produced lower SI and peak accelerations during the NOCSAE impact tests than the helmet alone. if a football helmet equipped with the Guardian Cap performs better on the NOCSAE impact tests than the same helmet without the Guardian Cap, as measured by SI and peak acceleration.

Conclusion

A Guardian Cap covered youth size large Schutt Recruit Hybrid football helmet does meet the NOCSAE football helmet standard. A Guardian Cap covered youth size large Schutt Recruit Hybrid football helmet does produce smaller Severity Indexes and peak accelerations during the NOCSAE impact than the helmet alone. These results lead to the conclusion that a Guardian Cap covered youth size large Schutt Recruit Hybrid football helmet can decrease head impact forces.

Applications

The results from the current study can be applied to various situations where further information about the effectiveness of the Guardian Cap can be utilized. This can be useful when high school and colleges are deciding whether or not to invest in the Guardian Cap for their athletes. For instance, a local Division 1A University just purchased Guardian Caps for use by athletes on their football team during practice session. Even though the Guardian Cap is not approved for game use in the NCAA, Syracuse University can be an example for future schools and the NCAA. If the Guardian Cap can produce the desired results with the teams who are using this over-helmet padding system now, the NCAA can look at those results, combined with the current literature and study, and make future decisions about the Guardian Cap in games. Caution should be noted when an athlete wears a Guardian Cap in practices but not in games. As stated previously by McIntosh and McCrory et. al, athletes may hit harder while wearing more padding because they perceive the hit will be decreased by the increased padding. The caution comes in when there is no more padding in game play and the athlete still hits the same way they have been hitting in practice, but without the extra over-helmet padding; this may cause an increase in head injuries.

Along with the NCAA, other medical professionals, parents, coaches and players can make informed decisions on whether or not to invest in a Guardian Cap. With this knowledge, researchers can also develop new technology to prevent future head injuries in sports, including concussions.

Recommendations for Future Research

When football athletes are playing and hitting other football athletes, there is more than one type of acceleration acting at any one point in a given time; this also applies to the helmet. One area for future research is an examination of head and helmet angular acceleration in vivo and the development of a standard for measuring testing angular acceleration of a helmeted headform. The current NOCSAE football helmet standard is based on linear acceleration produced during an impact. Further research should be considered where the Guardian Cap and helmet are put into scenarios where there are other types of accelerations that are not only linear.

Other future research should focus on real-life testing. This real-life testing can include human testing, environmental testing and multiple impact testing. Human testing can be completed on various levels of athletes (college, high school, etc.) over the course of a season or multiple seasons to determine a long-term effectiveness of the Guardian Cap. With human testing, researchers can also look at how the athlete responds to wearing a Guardian Cap and what possible modifications the athlete makes in their playing style. Researchers should examine the interaction of the Guardian Cap with different surfaces including another player’s jersey or padding, turf or even another player’s helmet. Environmental testing can also be completed with the in season human testing or in the lab. This environmental testing should include different weather conditions such as rain, extreme heat or mud. All of this real-life testing should include the facemask since the facemask was removed for this study to be in compliance with NOCSAE standards. With human testing, the increased risk of injury during Guardian Cap use should also be investigated. The Guardian Cap is an awkward shape due to the padding placement. Further research should look at the injury risk of wearing a Guardian Cap as it may catch on other players’ jerseys or padding.

Lastly, in football games many football athletes can get hit more than once. Future research should address the performance of the Guardian Cap after multiple impacts in a short amount of time. During the NOCSAE drop impact testing, after multiple drops of the helmet outfitted with Guardian Cap, the padding on the front of the Guardian Cap started to compress. For this reason, further research should be conducted on the short and long term integrity of the padding inside the Guardian Cap.

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APPENDIX

NOCSAE IMPACT TEST REPORTS

Protective Headgear Laboratory Data Sheet
To NOCSAE Doc. ND001-11m11 and 002-11m12

ITS Order No.: N/A

Client/Manufacturer: N/A

Brand Name: Schutt

Model/Size: Recruit Hybrid / Large

Lab Temp.: 68 - 74 °F

Required Temp.: 72.0°F +/- 5°F

NOCSAE Headform Size: Medium

Lab Humidity: 45 - 59 %

Required Humidity: 25 - 75%

Impact Surface: ½ " MEP Pad #21100203

Initial Ambient Impacts – Sample 1 (With GC)				
Impact Location	Velocity Requirement (m/s)	Actual Velocity (m/s)	Severity Index	Peak Acceleration (g)
Front Boss	3.46 - 3.56	3.51	59	48
Front Boss	5.46 - 5.62	5.57	287	86
Front Boss	5.46 - 5.62	5.49	287	86
Front	3.46 - 3.56	3.48	109	61
Front	4.23 - 4.36	4.33	139	62
Front	4.88 – 5.03	5.03	177	60
Front	5.46 - 5.62	5.56	259	75
Front	5.46 - 5.62	5.56	249	73
Right Side	3.46 - 3.56	3.51	91	58
Right Side	4.23 - 4.36	4.30	195	75
Right Side	4.88 - 5.03	4.97	314	92
Right Side	5.46 - 5.62	5.56	455	110
Right Side	5.46 - 5.62	5.57	457	111
Rear Boss	3.46 - 3.56	3.46	108	56
Rear Boss	5.46 - 5.62	5.58	530	105
Rear Boss	5.46 - 5.62	5.61	527	104

Notes:

Date: 5/23/14 Technician: Daniel Smith Reviewer: [signature] 5/23/14

Protective Headgear Laboratory Data Sheet
To NOCSAE Doc. ND001-11m11 and 002-11m12

ITS Order No.: N/A

Client/Manufacturer: N/A

Brand Name: Schutt

Model/Size: Recruit Hybrid / Large

Lab Temp.: 68 - 74 °F
Required Temp.: 72.0°F +/- 5°F
NOCSAE Headform Size: Medium

Lab Humidity: 45 - 59 %
Required Humidity: 25 - 75%

Initial Ambient Impacts – Sample 1 (continue) (With GC)				
Impact Location	Velocity Requirement (m/s)	Actual Velocity (m/s)	Severity Index	Peak Acceleration (g)
Rear	3.46 - 3.56	3.50	152	63
Rear	5.46 - 5.62	5.56	751	120
Rear	5.46 - 5.62	5.56	728	118
Top	3.46 - 3.56	3.56	163	63
Top	5.46 - 5.62	5.56	498	107
Top	5.46 - 5.62	5.57	487	100
Random	3.46 - 3.56	3.48	63	50
Random	5.46 - 5.62	5.56	397	103
Random	5.46 - 5.62	5.58	377	101

Notes: Random location = Left Side.

High Temp.: 115 - 117 °F
Required Temp.: 115°F +/- 5°F
Impact Surface: ½ "MEP Pad #21100203

Repeat High Temperature – Sample 1 (With GC)				
Impact Location	Velocity Requirement (m/s)	Actual Velocity (m/s)	Severity Index	Peak Acceleration (g)
Right Side	5.46 - 5.62	5.56	426	104
Right Side	5.46 - 5.62	5.56	476	113

Notes:

Date: 5/23/14 Technician: Daniel Smith Reviewer: [signature] 5/29/14

Protective Headgear Laboratory Data Sheet
To NOCSAE Doc. ND001-11m11 and 002-11m12

ITS Order No.: N/A

Client/Manufacturer: N/A

Brand Name: Schutt

Model/Size: Recruit Hybrid / Large

Lab Temp.: 68 - 74 °F

Required Temp.: 72.0°F +/- 5°F

NOCSAE Headform Size: Medium

Lab Humidity: 45 - 59 %

Required Humidity: 25 - 75%

Impact Surface: ½ " MEP Pad				
Initial Ambient Impacts – Sample 2 (Without GC)				
Impact Location	Velocity Requirement (m/s)	Actual Velocity (m/s)	Severity Index	Peak Acceleration (g)
Front Boss	3.46 - 3.56	3.46	51	45
Front Boss	5.46 - 5.62	5.50	359	102
Front Boss	5.46 - 5.62	5.49	365	103
Front	3.46 - 3.56	3.53	71	55
Front	4.23 - 4.36	4.30	121	54
Front	4.88 - 5.03	5.01	253	78
Front	5.46 - 5.62	5.50	298	82
Front	5.46 - 5.62	5.56	304	78
Right Side	3.46 - 3.56	3.48	96	56
Right Side	4.23 - 4.36	4.27	203	77
Right Side	4.88 - 5.03	4.96	330	95
Right Side	5.46 - 5.62	5.56	508	120
Right Side	5.46 - 5.62	5.62	501	115
Rear Boss	3.46 - 3.56	3.48	146	57
Rear Boss	5.46 - 5.62	5.62	612	110
Rear Boss	5.46 - 5.62	5.56	576	109

Notes:

Date: 5/23/14 Technician: Daniel Smith Reviewer: [signature] 5/29/14

Protective Headgear Laboratory Data Sheet
To NOCSAE Doc. ND001-11m11 and 002-11m12

ITS Order No.: N/A

Client/Manufacturer: N/A

Brand Name: Schutt

Model/Size: Recruit Hybrid / Large

Lab Temp.: 68 - 74 °F

Required Temp.: 72.0°F +/- 5°F

NOCSAE Headform Size: Medium

Lab Humidity: 45 - 59 %

Required Humidity: 25 - 75%

Impact Surface: ½ " MEP Pad #21100203

Initial Ambient Impacts – Sample 2 (continue) (Without GC)				
Impact Location	Velocity Requirement (m/s)	Actual Velocity (m/s)	Severity Index	Peak Acceleration (g)
Rear	3.46 - 3.56	3.48	216	72
Rear	5.46 - 5.62	5.62	842	135
Rear	5.46 - 5.62	5.56	829	130
Top	3.46 - 3.56	3.48	170	78
Top	5.46 - 5.62	5.52	521	99
Top	5.46 - 5.62	5.57	514	95
Random	3.46 - 3.56	3.51	95	55
Random	5.46 - 5.62	5.56	463	110
Random	5.46 - 5.62	5.58	465	116

Notes: Random location = Left Side.

High Temp.: 115 - 117 °F

Required Temp.: 115°F +/- 5°F

Impact Surface: ½ "MEP Pad #21100203

Repeat High Temperature – Sample 2 (Without GC)				
Impact Location	Velocity Requirement (m/s)	Actual Velocity (m/s)	Severity Index	Peak Acceleration (g)
Right Side	5.46 - 5.62	5.62	486	114
Right Side	5.46 - 5.62	5.61	537	121

Notes:

Date: 5/23/14 Technician: Daniel Smith Reviewer: [signature] 5/29/14