DEHYDRATION, CORE BODY, WET BULB GLOBE, AND IN-HELMET TEMPERATURE: POSSIBLE PREDICTORS OF IMPACT MAGNITUDE

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Abstract

ADAM ZACKERY SUMRALL: Dehydration, Core Body, Wet Bulb Globe, and in Helmet Temperature: Possible Predictors of Impact Magnitude
(Under the direction of Kevin M. Guskiewicz)

The purpose of this study was to determine if dehydration, core body, wet bulb globe, and in-helmet temperature are predictors of impact magnitude in 18 Division I football athletes at the University of North Carolina at Chapel Hill. The second purpose was to determine if the HIT System thermister is a valid device for measuring core body temperature. A prospective study was conducted utilizing the Head Impact Telemetry System to record and classify impact magnitudes and in-helmet temperature. A WBGT recorded environmental conditions and the CorTemp™ Ingestible Thermometer System recorded core body temperature. Data were collected during four practices through the 2009 fall season. Collected data were analyzed and resulted in no significant predictors of impact magnitude. Overall, our findings suggest impact magnitude cannot be predicted by these conditions, and the in-helmet thermister is not valid for measuring core body temperature.

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PREFACE

I had my first encounter with concussions and dehydration when I was in undergraduate school at the University of Southern Mississippi. In the summer of 2006, I was working as an athletic training student assisting at training camp for the university football team. The climate in south Mississippi in August is hot, humid and almost unbearable. I remember working hard making sure guys stayed hydrated during practice. Practices were very demanding for the athletes and the coaching staff expected physical play. After practice, guys would report into the athletic training room with signs of dehydration, but I had just learned about concussions and dehydration and realized that both had a lot of similar signs and symptoms. I started questioning how someone distinguishes between a concussion and dehydration. I quickly learned different methods for distinguishing between the two issues. I knew how to distinguish between the two, but I began to wonder whether or not dehydration or environmental conditions can have an effect on the impact magnitude individuals suffer during competition. During my short career as an athletic trainer, I have encountered more concussions during the hot and humid days than cooler days. The curiosity of whether environmental conditions or dehydration have an affect on impact magnitude has led me to perform this study.

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LIST OF ABBREVIATIONS

A-E - Athletic Exposures

HIT System- Head Impact Telemetry System

NCAA- National Collegiate Athletic Association

NOCSAE- National Operating Committee on Standards for Athletic Equipment

WBGT- Wet Bulb Globe Temperature

CHAPTER I

INTRODUCTION

For many years, concussions have been a major clinical concern for sports medicine professionals. Though it is a relatively common injury in athletics, there is a surprising lack of understanding in how concussions can be prevented or reduced. It is estimated that 1.6 to 3.8 million concussions occur each year. (Langlois et al., 2006) Second to motor vehicle accidents, sports are the leading cause of concussion among teenagers and young adults. (Sosin et al., 1996) The recognition and management of concussions has been widely studied and strongly established; however, there are areas pertaining to concussion prevention that still need to be explored.

Another medical issue clinicians often deal with during sports participation is dehydration. Dehydrated and concussed individuals experience overlapping symptoms. In a study conducted by Patel et al., subjects who were dehydrated complained of symptoms comparable to concussed individuals. (Patel et al., 2007) These symptoms included balance deficits, feeling slowed down, difficulty concentrating, difficulty remembering, and disorientation. Dehydration is the body's loss of fluid through sweat or secretion and occurs when these exceed the amount of replenishing fluids. (Thomas et al., 2008) Dehydration, if left untreated, will progressively lead to decreased sweat production and encumbers the body's ability to dissipate heat through evaporation. Sweat evaporation plays a direct role with the regulation of core body temperature. (Casa et al., 2000) Core temperature is a true measure of the degree of heat that is produced by the body and is maintained between 35 and 38°C. (Maughan et al., 2007) When core temperature remains elevated above 37^{o} C, a wide array of physiological changes occur in an attempt to maintain homeostasis. (Armstrong et al., 2007)

The football field serves as a research laboratory for many concussion and dehydration specialists. Though the two conditions share some significant overlap, very little research has endeavored to better understand the relationship between impact magnitudes, environmental conditions, core body temperature, and dehydration. Sideline clinicians are faced with the task of differentiating between dehydration or a concussion, on a regular basis, but also they must regulate rest periods during practice when environmental conditions are extreme. In recent years, novel helmet instrumentation capable of recording linear and rotational head acceleration has been embedded in football helmets. As a result, concussion researchers have been able to better characterize the head impacts sustained by collegiate and high school football players. (Broglio et al., 2009; Guskiewicz & Mihalik, 2007) These studies have also looked at impact accelerations and how they pertain to location and clinical outcome of symptomatology, neuropsychological, and postural stability. (Guskiewicz & Mihalik, 2007) Positional and event type differences have been established in collegiate and high school football and the relation of high and low impact magnitudes to clinical measures have also been studied. (Broglio et al., 2009; McCaffrey et al., 2007; Mihalik et al., 2007) Separately, the study of heat illness in collegiate and professional football players has also been extensively researched in recent years; leading clinicians to better management of these conditions. (Godek et al., 2006; Yeargin et al., 2006) To date, no known study has been conducted to determine if dehydration, core body temperature, wet bulb globe temperature (WBGT), or in-helmet temperature are predictors of head impact magnitude.

Purpose Statement

The primary purpose of this study is to investigate if increases in dehydration, changes in core body temperature, WBGT, and in-helmet temperature predict head impact magnitudes. As a follow-up to the primary purpose, we want to determine if any of the variables will predict impact magnitude individually. The secondary purpose of this study is to determine if the HITS accelerometer thermister is a valid device for measuring core body temperature. The third purpose of this study is to determine if impact magnitudes are statistically different between data collection days. The final purpose of this study is to establish if there is a relationship that exists between core body temperature and in-helmet temperature, core body temperature and ambient temperature, core body temperature and WBGT.

Statement of the Problem

Collegiate football is a sport that begins in early August and can continue through until early January. During the football season many different environmental conditions are encountered. These seasonal conditions can range anywhere from hot to cold or humid to dry. Clinicians have noticed a trend that football players tend to suffer more concussions during the hot periods of the season as compared to the cooler periods. The increased number of concussions during the warmer days of the season might have a link with environmental conditions. Elevated core body temperatures are a concern during the hotter months of the season, but as the environmental temperature cools the risk of heat related illnesses declines and concussions seem to follow the same path. Impact magnitudes may change with the seasons. Maybe during the hotter days of football season athletes are subjected to greater impact magnitudes than they are during the cooler days. If this trend is true, it could change the way practice sessions are held and would provide another reason for clinicians to encourage the consumption of fluids. No studies as of yet have attempted to find a link between seasonal conditions and impact magnitudes.

Sports medicine professionals are constantly challenged with the task of determining the best approach for handling sport related concussions and dehydration. Techniques have been utilized to help reduce the number of heat related illnesses, but only a handful of techniques have been employed to help reduce the number concussions during football competition. By investigating dehydration, core body temperature, environmental conditions and impact magnitudes; sports medicine professionals will have a better understanding on how to alter practices and possibly reduce the number of concussions.

Research Questions

1. Do dehydration, core body temperature, WBGT, and in-helmet temperature predict impact magnitude across four test days during the fall season?
2. Do dehydration, core body temperature, WBGT, and in-helmet temperature individually predict impact magnitude across four test days during the fall season?
3. Do the three training camp sessions differ in impact magnitude when compared to the control session?
4. Is the HIT system thermometer a valid device for measuring core body temperature?
5. What is the relationship between:
    a. Core body and in-helmet temperature?
    b. Core body and ambient temperature?

c. Core body and WBGT?

Null Hypotheses

1. Dehydration, core body, WBGT and in-helmet temperature does not predict impact magnitude across four test days during the fall season.
2. Dehydration, core body, WBGT and in-helmet temperature does not individually predict impact magnitude across four test days during the fall season.
3. The three training camp sessions do not differ in impact magnitude when compared to the control session.
4. The HIT system thermister is not a valid device for measuring core body temperature.
5. There is no relationship between:
    a. Core body and in-helmet temperature.
    b. Core body and ambient temperature.
    c. Core body and WBGT.

Research Hypotheses

1. Dehydration, core body, WBGT, and in-helmet temperature will be strong predictors of impact magnitude across four test days during the fall season.
2. Dehydration core body, WBGT, and in-helmet temperature will not individually be strong predictors of impact magnitude across four test days during the fall season.
3. There will be a statistical difference between the three training camp sessions and the control session.
4. The HIT system thermister will not be a valid device for measuring core body temperature.
5. There will be a strong relationship between:

a. Core body and in-helmet temperature.

b. Core body and ambient temperature.

c. Core body temperature and WBGT.

Definition of Terms

1. **Impact magnitude**: The amount of linear or rotational acceleration produced when a helmet strikes another object or when a player is tackled causing an acceleration-deceleration force.
2. **WBGT**: The measure of warmth or coldness of external factors which includes humidity and radiant temperature surrounding and affecting an individual.

Limitations

1. Subjects unable to complete the study due to injury sustained during the testing period.
2. Environmental conditions cannot be controlled, and will have differing affects on subjects.

Delimitations

1. Division I football athletes between the ages 18-24 years.
2. Players consisted of defensive and offensive linemen and defensive and offensive backs and wide receivers.
3. No kickers or quarterbacks were included in the study.
4. Data collection occurred over four days during the season.
5. A presence of any known gastrointestinal tract disease.
6. Impairment or disorders of gag reflex.
7. Previous gastrointestinal surgery.

8. Subjects' diet was not controlled.

Assumptions

1. The HIT system provided accurate information about location and magnitude of impacts to the head.
2. The HIT system provided correct readings of in-helmet temperature.
3. The WBGT provided a correct measure of the environmental conditions.
4. The refractometer analyzed urine specific gravity correctly.
5. The weight scale provided accurate measurements during each test day.

Significance of the Study

Since a portion of the football season is played during August, one of the hottest and most humid months in the year, clinicians need to know how dehydration, increasing core body and environmental temperatures relate to impact magnitudes. Relating impact magnitude with these variables to our knowledge has not yet been investigated. While dehydration and concussion present similar symptoms, no one has taken into account if elevated physiological conditions or environmental temperatures may place football players in a position to experience greater impact magnitudes. Research needs to be conducted to determine if dehydration, increasing core body, WBGT, and in-helmet temperature predict impact magnitudes. If these factors predict impact magnitude, clinicians would have another reason for altering practices and encouraging hydration and demanding cool down periods during adverse environmental conditions.

Many football practices begin with the least amount of contact early and progress to more contact oriented drills later in practice. Initially, at the start of practice, athletes core body temperatures may not be far from the normal temperature of 37^{o} C. As the athletes progress through drills dehydration and elevating core temperatures begin to be an issue. Maybe the best routine for practice is to have the more contact oriented drills early during practice when athletes are better hydrated and their core body temperature is closer to a homeostatic state.

CHAPTER II

REVIEW OF THE LITERATURE

Athletes have become bigger, faster, and stronger compared to athletes 40 years ago causing American football to move from a contact sport to a collision sport. In the late 1960s, the greatest number of catastrophic brain injuries occurred in American football, but there has been a tremendous decrease in the number of incidences since this time. (Boden, 2005) The decline has been attributed to equipment and rule changes. Equipment changes were made to helmets, and the National Operating Committee on Standards for Athletic Equipment (NOCSAE) established safety standards helmets had to meet before use on the playing field. (Boden, 2005) Since the advent and mandatory use of the NOCSAE approved modern day football helmet, the occurrence of catastrophic head injuries in football has remained low. In 1990, zero fatalities were reported and the average has been hovering around eight to ten catastrophic head injuries per year since. (Levy et al., 2004; Mueller, 2003) Rule changes have also played a major role in the decline of catastrophic head injuries. American football players are no longer allowed to spear or butt block, perform intentional helmet to helmet contact, initiating contact with and targeting a defenseless opponent, or tackling an opponent with the neck collar have been removed from football.

Heat related illnesses are a major concern during athletic participation, especially in equipment intensive sports which participate in high heat and humid conditions. Experts have established guidelines to provide athletes with the best chance of success in the heat. Football training camp begins in early August, which is one of the hottest months in the year for the majority of regions in the United States. Rules have been established by the NCAA Proposal No. 2002-84 regarding heat acclimatization during training camp and have been in effect since the 2002-2003 football season. The proposal mandates a five day acclimatization period at the beginning of training camp. During the acclimatization period, only one practice a day is allowed, and the first two practices are helmets only. The third and fourth days of practice can be conducted in helmets and shoulder pads, and on the fifth day full pads can be worn. On days of multiple practices, teams are only allowed to be on the field for a total of five hours with a minimum of a three hour recovery period between practices. During days consisting of single practices, athletes can not be on the field for longer than three hours. The rules mandated by the NCAA Proposal No. 2002-84 proved to help athletes acclimatize to the environmental conditions. (Yeargin et al., 2006) Heat illness conditions are ordinary to this sport and season and present a threat to an athlete's health, but clinicians take measures to reduce the chance of occurrence.

Concussion and dehydration have shown similarities between each other. Many symptoms overlap between the two conditions including headache, nausea, vomiting, balance deficits, dizziness, sensitivity to light or noise, and nervousness. (Patel et al., 2007) Clinicians provide fluids and other opportunities for athletes during practice to lower body temperature and rehydrate, but more clinically objective measures, interventions, or material adjustments need to be established to help control vulnerable athletes from suffering greater impact magnitudes.

Concussion

Many definitions of concussion exist in the literature. Concussion derives from the Latin word, *concussus*, which means to shake violently. Loss of consciousness used to be the one sign defining a concussion, but this is no longer accepted in the sports medicine world since concussion can be present without loss of consciousness. Concussion is defined as an alteration in the physiological processes due to biomechanical force that affects the brain, and results in impairment of neurological function resulting in one or more symptoms including headache, nausea, vomiting, dizziness, balance deficits, drowsiness, sensitivity to light or noise, blurred vision, difficulty remembering or concentrating. (Cantu, 2007; Giza & Hovda, 2001; Guskiewicz et al., 2004) Resulting symptoms from concussion may resolve within a matter of minutes but can last for days or even months.

Epidemiology of Concussion

Concussions are estimated to occur 1.6 to 3.8 million times each year in the United States. (Langlois et al., 2006) American football is commonly associated with the highest incidence of concussion in athletics, but this trend is due to the large number of participants across the United States. According to Sosin et al., sports are the second leading cause of concussion, with the leading cause being motor vehicle accidents. (Sosin et al., 1996) Data collection from the NCAA Injury Surveillance System between 1988-2004 football seasons suggest concussions accounted for 6.8 percent of injuries during fall games (frequency of 2,085), 5.5 percent during fall practices (frequency of 2,319), and 5.6 percent during spring practices (frequency of 612). (Dick et al., 2007) Guskiewicz et al. reported similar findings, stating the overall incident of concussions was 0.81 per 1,000 athlete exposures (A-E) during a three--year prospective study. (Guskiewicz et al., 2003) More than half of the concussions reported occurred during practice, but game concussion rates were noticeably higher at 8.15 per 1,000 A-Es. (Guskiewicz et al., 2003) The injury surveillance system information gathered during 1988-2004 determined in game injury ratio for concussion to be 2.34 per

1,000 A-Es, and the probability of sustaining a concussion during a fall game is 11 times more likely than in fall practice. (Dick et al., 2007) The injury rates of concussion have been reported between 0.21-0.81 per 1,000 A-Es during practice and 1.28-2.34 per 1,000 A-Es during game situations. (Dick et al., 2007; Guskiewicz et al., 2003) The differences between practice and game situations are attributed to greater intensity during game situations.

Anatomy of the Brain

Cranial Meninges

Three cranial meninges encase and create a circulatory system for the brain. The outermost layer is the dura mater, the middle layer is the arachnoid mater, and the innermost meninge is the pia mater. The dura mater is a thick tough membrane which attaches to the internal side of the cranium and the outermost surface of the arachnoid mater. The arachnoid mater is a thin membrane with collagen fibers interacting with the dura and pia mater. The pia mater covers every surface of the brain and is located below the arachnoid mater. The cranial meninges help stabilize the shape and control the location of nerve tissue within the brain by inter-digitating with one another. As the cranium moves, the brain is forced to move with it due to the connections between cranial meninges. (Nolte, 1993)

Cerebrospinal Fluid

Cerebrospinal fluid is located within the meninges and provides a buoyant effect to the brain. Specific cells called ependymal cells secrete cerebrospinal fluid into the ventricles of the brain. The floating effect created by the fluid decreases the tendency of external forces to distort the brain and keeps the cranial nerves and blood vessels from being compressed on the inferior surface of the skull. (Moore & Dalley, 2006; Nolte, 1993) The cerebrospinal plays a critical role in shock absorption when the head is subjected to external forces. Once subjected to linear or rotational forces, the brain is unable to move in unison with the skull because of the lag created by the cerebrospinal fluid. Once the skull begins to move in another direction the brain will continue to move forward until it strikes the portion of the cranium where the force was initially directed. The spinal fluid helps convert directly applied stresses to compressive stresses by distributing the force across a broader area of the brain. (Cantu, 1996)

Frontal Lobe

Located from the anterior portion of the brain to the central sulcus and inferiorly at the lateral sulcus, the frontal lobe contains three prominent functional areas: the pre-frontal cortex, Broca's area, and the primary motor cortex. (Nolte, 1993; Orrison, 2008) The pre-frontal cortex is associated with memory functions and cognitive functions related to personality. Broca's area distinguishes words and facilitates language to be spoken. The primary motor cortex initiates, plans, and executes voluntary movement. (Orrison, 2008)

Temporal Lobe

The temporal lobe expands superiorly to the lateral sulcus and the inferior border of the parietal lobe. Posteriorly it extends to the parietooccipital sulcus and the pre-occipital notch. The medial surface is located from the pre-occipital notch to the splenium of the corpus callosum. (Nolte, 1993) The temporal lobe consists of the primary auditory cortex, visual and auditory association areas, and elements of the limbic system. (Orrison, 2008) The limbic system structures affiliated with the temporal lobe consist of the amygdala, the parahippocampal gyrus, and the hippocampus. These structures regulate emotions, visceral responses, learning, and memory. (Orrison, 2008)

Occipital Lobe

The occipital lobe is bound to the parietal and temporal lobes anteriorly on both hemispheres of the brain. (Nolte, 1993) The occipital lobe consists of the primary visual cortex and visual association cortex which work together in higher order processing of visual information. (Orrison, 2008)

Parietal Lobe

The parietal lobe begins at the central sulcus and extends to the top of the parietooccipital sulcus and the pre-occipital notch. It is positioned superior to the occipital lobe and posteriorly to the frontal lobe. (Nolte, 1993) The parietal lobe deals with primary and higher order somatosensory association areas. These areas integrate sensation, visual, and auditory information to determine spatial sense and navigation. (Orrison, 2008)

Cerebellum

The cerebellum is divided into anterior and posterior lobes. The anterior lobe receives a large amount of its afferent signals from the spinal cord and plays an important role in postural adjustments, and the posterior lobe receives most of its information from the cerebral cortex. The posterior lobe plays a role in the coordination of voluntary movements. All the information gathered from both lobes is interpreted at the cerebellum and creates coordinated motor movements. (Orrison, 2008)

Brainstem

The brainstem is formed by three separately identified regions known as the medulla oblongata, midbrain, and pons. The medulla oblongata connects the spinal cord and the brain, but it is associated with autonomic function as well. The medulla oblongata regulates the involuntary function of digestion, breathing, blood pressure, and heart rate. (Orrison, 2008) The midbrain is affiliated with auditory and visual processing, control of eye movements, and orienting behaviors. (Orrison, 2008) Transmission of information from the spinal cord to higher brain regions is regulated by the pons. The pons are linked to the regulation of arousal, blood pressure, and respiration. (Orrison, 2008)

Diencephalon

The diencephalon is composed of the thalamus and the hypothalamus. The thalamus is the gateway between the cortex and the basal ganglia, cerebellum, brain stem and spinal cord for all sensory information except smell. (Orrison, 2008) It regulates sensory information to the appropriate area of the cortex. The hypothalamus regulates homeostasis of the body's internal environment. Its neural centers regulate body temperature, fluid balance, neuroendocrine control, thirst, food intake, and sleep cycles. (Orrison, 2008)

Etiology of Concussion

Concussions may result from a number of mechanisms, but the most common consist of coup, contre-coup or a combination of the two. Coup injuries occur when a forceful blow is impacted on the moveable head causing damage to occur beneath the point of impact. (Guskiewicz et al., 2004) Coup mechanisms result in shock waves emanating from the impact point causing tissue strains to be placed on the brain. (Hardman & Manoukian, 2002) Contre-coup mechanisms occur when the head is moving and is suddenly stopped by an unyielding object resulting in tissue damage opposite the site of impact. (Guskiewicz et al., 2004; Hardman & Manoukian, 2002) Guskiewicz et al. states no scientific evidence claims coup or contre-coup injuries are more detrimental than the other or that signs and symptoms present differently. (Guskiewicz et al., 2004) Concussive sport injuries are most likely to occur due to a combination of coup and contre-coup injuries causing tissue damage through compressive, tensile, or shearing strains. (Cantu, 1996; Guskiewicz et al., 2004; Hardman & Manoukian, 2002)

The compressive, tensile, and shearing stresses are generated from acceleration or deceleration forces to the head. Compressive forces result in a crushing mechanism which causes damage to the underlying tissue, because it is unable to absorb the additional load. (Guskiewicz et al., 2004) Compression forces are endured by the neural tissue of the brain better than tensile and shearing forces, because the cerebrospinal fluid helps dissipate and absorb some of the force. (Cantu, 1996; Gennarelli, 1993) Tensile forces occur from tissue being stretched, and shearing forces are the result of forces moving in opposite directions parallel to one another. (Cantu, 1996; Guskiewicz et al., 2004) Cerebrospinal fluid does not have the capability to resist either tensile or shearing forces, and it is the main reason neural tissue tolerates these forces very poorly.

Pathophysiology of Concussion

Immediately after biomechanical stresses or cerebral concussion, ionic shifts occur at the axonal level resulting in changes of cellular physiology affecting neuronal activity. (Giza & Hovda, 2001) The diffuse axonal injury has been reported as the primary mechanism behind concussions. (Alexander, 1995) Cerebral blood flow is coupled with neuronal activity under normal conditions, but after brain impact, cerebral blood flow is reduced 50 percent. (Giza & Hovda, 2001) In an effort to restore ionic homeostasis, glucose expenditure increases to meet the energy demands required to correct the ionic disturbance. (Giza & Hovda, 2001) If the energy requirements can not be fulfilled by glucose expenditure, glycolysis will be utilized. (Giza & Hovda, 2001) Glycolysis is a metabolic pathway that converts glucose into pyruvate, and energy (ATP) is released during this process.

Dehydration and Core Temperature

Heat-related illnesses have many common signs and symptoms between each other, but the one symptom that has been shown to present like a concussion is dehydration. (Patel et al., 2007) Dehydration is determined by how much fluid is lost combined with the amount of fluid intake; however, it is not only affected by sweating and inadequate fluid intake, but vomiting, diarrhea, certain medications and alcohol or caffeine can place an individual at an increased risk for dehydration. (Binkley et al., 2002; Casa et al., 2000) Decreases in body weight of 1% to 2% can alter an individual's physiological ability to perform in strenuous activities and place adverse stress on regulating body systems. (Casa et al., 2000)

Giza and Hovda state cerebral blood flow is coupled with neuronal activity in normal conditions, and a concussive episode can result in a 50% decrease in cerebral blood flow. (Giza & Hovda, 2001) Hyperthermia and dehydration play a role in the reduction of cerebral blood flow. A study conducted by Nielson and Nybo found that subjects who were physically exerted in a dehydrated state had 18% less cerebral blood flow during the hyperthermia trials than during the normal trials. (Nielsen & Nybo, 2003) Athletes who are dehydrated or hyperthermic are not in a normal condition because any decrease in hydration decreases the amount of blood volume, decreases the stroke volume, and results in increases in core body temperature. Fluid volume whether its cerebrospinal fluid or blood within the cranium absorbs and dissipates brain movement. Dehydrated athletes may be susceptible to greater impact magnitudes due to the decrease in fluid. One particular study has shown with every 1 percent of weight lost due to sweating, the core body temperature may rise an additional 0.15 to 0.20^{o}C. (Montain & Coyle, 1992) When core temperature elevates above 37^{o}C (98.6^{o}F) due to dehydration, decreases in cognitive function may occur and be presented as headaches, balance problems, and irritability. (Armstrong, 2000; Patel et al., 2007) The rise in core temperature has an effect on the amount of fluid secretion and flow of blood throughout the body. In an attempt to regulate core temperature, the body must conduct many physiological sequences to maintain an optimal homeostatic state.

Thermoregulation

Thermoregulation is a key component to athletes performing in unfavorable environments and has been described as a complex interaction of the central nervous system, cardiovascular system, and the skin in an effort to maintain core body temperature of 37^{o}C. (Binkley et al., 2002; Murray, 1996) The hypothalamus is the central nervous system's center for thermoregulation, and it acts as a thermostat for the body's internal temperature. (Armstrong, 2000; Murray, 1996) The hypothalamus receives afferent input from many receptors regarding core and peripheral temperature and interprets the information, providing the brain with a course of action for regulating core temperature. (Armstrong, 2000; Binkley et al., 2002) In hot and humid environments, thermoregulation must work in an optimal fashion to maintain homeostasis. The brain sends out efferent signals to the skin, cardiovascular system, and endocrine system to alter physiologic functions, in attempt to maintain a steady core temperature. (Binkley et al., 2002) Epidermis has millions of sweat glands located just below its surface, and in response to heat regulation, the sweat glands excrete more fluids. (Armstrong, 2000) In conjunction with increased sweat production, the cardiovascular system increases the amount of cutaneous vasodilation shunting blood from central circulation to the periphery to promote heat loss. (Howe & Boden, 2007) To meet the requirements of distributing oxygenated blood to the cutaneous vessels and working muscles, heart rate, cardiac output, and respiratory rate increase. (Armstrong, 2000; Binkley et al., 2002; Howe & Boden, 2007) Athletes may be more susceptible to suffer greater impact magnitudes in this type of environment due to the decrease in blood volume in the brain. The blood within the brain can act along side cerebrospinal fluid like a shock absorber and help protect it from compressive episodes.

Football athletes have a great variation in the amount of sweat they secrete during practice. Normally offensive and defensive linemen are the largest individuals on the team followed by linebackers, running backs, defensive backs, and wide receivers. Linemen have been shown to have the greatest amount of sweat lose averaging 2385 mL/h. Offensive and defensive backs sweat at rates averaging 1410 mL/h which is comparable to the average sized male. (Godek et al., 2008) It is important to note that not only are linemen at greater risk of losing greater amounts of fluid during football practice, but they are also subjected to more repeated impacts during practice than the other positions. Mihalik et al. performed a study looking at positional impact differences and discovered that linemen accounted for 32,796 of 57,024 impacts recorded during two years of seasonal fall football. (Mihalik et al., 2007) In the same study, the running backs and linebackers accounted for 12,958, and the wide receivers and defensive backs attributed 11,270 of the total 57,024 impacts.

Thermoregulation centers utilize four types of heat dissipation mechanisms to help decrease core temperature:

Radiation

Radiation refers to energy transfer to and from an object or body that is released to the external environment via infrared rays. (Brewster et al., 1995) For energy to be transferred, the body has to be greater in temperature than the outside environment. (Brewster et al., 1995; Casa et al., 2000)

Conduction

Conduction is the transfer of heat from warmer to cooler objects, but only through direct contact between objects. (Brewster et al., 1995) Conduction occurs when an ice bag is placed on an athlete. Heat transfers from the athlete to the ice bag. Conduction is a process that is assisted by convection.

Convection

Convection involves the transfer of heat to and from the body to surrounding moving fluid which can be air or water. (Casa et al., 2000) Convection assists conduction by removing the heat surrounding the body. (Brewster et al., 1995)

Evaporation

Evaporation is characterized by heat transfer via the vaporization of sweat and functions as the principal mechanism for heat loss. (Brewster et al., 1995; Casa et al., 2000) Evaporation only occurs when the ambient temperature is greater than body temperature and is the most effective form of heat loss. (Brewster et al., 1995) With every gram of sweat lost due to evaporation, 0.58 calories of heat is lost. (Brewster et al., 1995)

Performance

Performance declines due to the body's inability to maintain an optimal internal environment when it is dehydrated or when core body temperature is in an elevated state. Casa et al. explains that dehydration of 1% to 2% of body weight begins to negatively affect performance. (Casa et al., 2000) A study looking at the effects of hydration state on strength, power, and resistance exercise performance found that dehydration had little effect on single, maximal effort on strength and power, but it limited the endurance of resistance trained males when performing a squat protocol. (Judelson et al., 2007) Another study assessing performance tested subjects in a euhydrated and dehydrated state. Each subject completed three walking treadmill trials to exhaustion in a euhydrated state and two dehydrated states at 2 percent and 4 percent less body mass. During the dehydrated trials, subjects' work performance dropped by 18-44 percent when compared to the euhydrated subjects. (Craig & Cummings, 1966) A study conducted by Kraft et al supports the fact that dehydration causes a decrease in performance. During their study, the researchers placed subjects in a strenuous exercise protocol in a dehydrated state of approximately 3% of the pre-test body weight, and a heat exposure condition with fluid replacement. The exercise protocol lasted approximately 45 minutes. During the dehydrated condition, the subjects on average were only able to complete 144 repetitions which were significantly lower than the heat exposure condition. Subjects averaged 169 repetitions during the heat exposure condition. (Kraft et al.) These studies support the fact that dehydration hinders athletic performance.

One study looking at the affects of core body temperature on two minute maximal voluntary contraction found that individuals in a normal state performed better than the hyperthermia subjects. The normal trail resulted in 82% maximal voluntary contraction at the end of two minutes, but in the hyperthermia trial, subjects were only able to produce 54% of their maximal voluntary contraction. (Nielsen & Nybo, 2003) During training camp, the vulnerability to greater impact magnitudes could increase because it is a high demanding two to three weeks of physical activity. Practicing repeatedly in heat and humidity could result in decreases in hydration and increases in core body temperature during practice.

Second Impact Syndrome

Second impact syndrome occurs when an individual suffers another head injury before the brain has recovered from the first concussive episode. The first episode results in neurological deficits and places the brain in a more vulnerable state, but when a second impact occurs these deficits are magnified. (Cobb & Battin, 2004) Three stages of vulnerability exist where an individual is at an increased risk of irreversible tissue damage to occur after a first initial concussion. During the time period of cerebral blood flow reduction, cerebral metabolism is at its limit and an increase in energy demand or a decrease in energy stores may place the recovering tissue in an irreversible state of neuronal injury. (Giza & Hovda, 2001) Another stage of vulnerability revolves around calcium accumulation. If calcium levels have not been restored to their normal state and a second impact is encountered, there will be an additional influx of calcium and may result in the activation of proteases which leads to cell death. (Giza & Hovda, 2001) The third stage involves impairment of neurotransmission which results in cognitive dysfunction. (Giza & Hovda, 2001) If a second impact occurs while neurotransmission is decreased, attention and cognition will be greatly altered. (Giza & Hovda, 2001)

For second impact syndrome to occur a direct blow does not have to occur, but it can occur from an indirect mechanism causing the head to be subjected to violent acceleration or deceleration forces. (Proctor & Cantu, 2000) The athlete who is suffering from second impact syndrome will present stunned, with rapidly dilating pupils, fixed eye movements, and can experience rapidly deterring symptoms. (Proctor & Cantu, 2000) Second impact syndrome is a medical emergency, and the suffering individual is to be referred to the emergency room immediately.

Methodological Considerations

Wet Bulb Globe Temperature

The WBGT gauge is a digital device used for measuring environmental conditions. The apparatus is beneficial because it allows clinicians a method of measuring ambient temperature, relative humidity, and black globe temperature with ease and accuracy. The WBGT index was recommended in a position statement by the National Athletic Trainers Association on exertional heat related illness as a guideline to modify activity levels during athletic events. (Binkley et al., 2002) According to the WBGT index environmental temperatures above 27.8^{o}C is in the very high risk region, and the high risk area is between 22.8 and 27.8^{o}C. (Coris et al., 2004) The moderate WBGT range is 18.3 to 22.8^{o}C, and the low risk temperature is anything below 18.3^{o}C. (Coris et al., 2004) Wet bulb globe variables have been used by researchers in studies to relate ambient temperature readings to heat acclimatization and core body temperature in football athletes. (Godek et al., 2004; Yeargin et al., 2006)

CorTemp™ Ingestible Core Body Temperature System

The CorTemp™ Ingestible Core Body Temperature System is a device that is growing in popularity. The system is being used to monitor the core temperature of athletes and firemen during physical activity. The device is small, easily carried and used, while monitoring individuals. The system can be too costly for many sports medicine programs to utilize, because the measurement and tracking equipment can cost $1,995 and each pill cost $37. The ingestible transmitter has been proven valid in studies comparing different methods of core temperature measurement to the gold standard rectal temperature during indoor and outdoor exercise in the heat. (Casa et al., 2007; Ganio et al., 2009) Of all the methods, the ingestible thermometer demonstrated to be the only valid measurement of core body temperature. (Casa et al., 2007; Ganio et al., 2009) Ingestible thermisters have been used successfully to measure core body temperature in football athletes during competition. (Yeargin et al., 2006) Yeargin et al. used the ingestible thermisters to study acclimatization of football athletes during training camp. The researchers were able to record intestinal temperature readings before, during, and after practice.

Head Impact Telemetry System

The Head Impact Telemetry (HIT) System is a novel device with the capability of measuring in helmet temperature, helmet impact location, number of impacts, and linear and rotational head acceleration forces in real time. The instrument is being utilized to study factors affecting concussion severity. Previous studies have utilized the impact location, number of impacts and linear and rotational head acceleration force information detected by the system. In a study conducted by Duma et al., the HIT system was used to measure head impacts over an entire football season. During the study, 3,312 valid impacts were recorded from 38 different players covering both offensive and defensive positions. (Duma et al., 2005) The HIT system proved effective for the researchers and provided information on impact location, number of impacts sustained, and linear and rotational head acceleration magnitudes. To date no known studies have used the accelerometer thermister to gather in-helmet temperature.

Refractometer

The refractometer is a hand held device used to measure hydration levels. It is reusable and in the long run more cost effective than urine test, but more objective than urine color charts. The device used for this study will be digital and simple to administer when testing subjects.

CHAPTER III

METHODOLOGY

STUDY DESIGN

Eighteen Division I male collegiate football athletes between the ages of 18 and 23 years old who were already enrolled in an on going study were recruited. The subjects' height, weight, and age are depicted in *Table 1*. Our sample includes subjects from each playing position category. These categories were established by grouping the offensive and defensive positions together by similar athletic build. The running backs were matched with the linebackers. The wide receivers were grouped with the defensive backs, and the offensive linemen were matched with the defensive linemen. Quarterbacks and kickers were excluded from the study due to their lack of contact during practice. Subjects were excluded if a known gastrointestinal tract disease was present; impairment or disorders of the gag reflex, and any previous gastrointestinal surgery. Subjects signed a consent form approved by The University of North Carolina Institutional Review Board before participation in this study.

Equipment

Head Impact Telemetry (HIT) System

The Head Impact Telemetry (HIT) System is a relatively novel device with the capability of measuring in helmet temperature, helmet impact location, number of impacts, and linear and rotational head acceleration forces in real time. The HIT System obtains data from accelerometer units comprised of six spring-mounted single-axis accelerometers, a data storage device, and a battery pack housed within a waterproof plastic shell embedded within Riddell VSR-4, Revolution, or Revolution Speed football helmets (Riddell Corp., Elyria, OH) *(Figure 1)*. The HIT System accelerometer is equipped with a thermister designed to measure temperature within the helmet. Temperature data is sent wirelessly with each impact data packet. The data were time stamped, encoded, stored locally, and then transmitted in real time to a sideline controller (antenna) incorporated within the Sideline Response System (Riddell; Elyria, OH) via a radiofrequency telemetry link *(Figure 2)*.

The sideline controller was located within the athletic training room adjacent to the practice fields. The sideline controller loads the impact information into a laptop encased in a sturdy rolling case which allows the device to be mobile and provides the laptop protection. Biomechanical measures of head impact severity were computed and stored. The HIT System is capable of transmitting accelerometer data from as many as 100 players over a distance well in excess of the length of a standard American football field. In some instances when the real-time transmission of data was unavailable, information from 100 separate head impacts are capable of being stored in non-volatile memory built into the acceleration monitoring system and can be later downloaded.

CorTemp™ Ingestible Core Body Temperature System

The CorTemp™ Ingestible Core Body Temperature Sensor (model HT150002; HQ Inc., Palmetto, FL) is a novel and valid ingestible temperature transmitter that has been approved for ingestion by the Food and Drug Administration *(Figure 3)*. (Casa et al., 2007; Ganio et al., 2009) The sensor wirelessly transmits core body temperature readings as it travels through the digestive system at a frequency of 262 kHz. The sensor’s signal is received wirelessly by the Data Recorder (model HT150001) and converts the signal into digital format *(Figure 4)*. It is capable of displaying temperature in real time and stores data for download and later analysis.

During data collection, the temperature readings were hand written onto an excel spreadsheet in case issues occurred while transferring the data from the recorder to the application software. The hand written information was transferred to digital format in an Excel spreadsheet for analysis. Each time temperature readings were being collected, the measurement was taken twice to ensure no mistakes occurred during collection.

Wet Globe Bulb Thermometer

The Heat Stroke Checker (WBGT 103F) is a digital WBGT that is used to record ambient temperature, relative humidity, and black globe temperature. The WBGT index is derived from three independent environmental readings: dry bulb temperature (ambient air temperature), wet bulb temperature (humidity), and black globe temperature (radiant heat). (Binkley et al., 2002; Cooper et al., 2006) The index provides clinicians with objective measures to make appropriate determinations on the intensity, length, time of day, and required rest periods in unfavorable conditions. (Cooper et al., 2006)

Refractometer

The refractometer is a simple digital hand held device (Misco Products Division, Cleveland, OH) used for the evaluation of dehydration status by measuring urine specific gravity levels. The Misco refractometer was tested for reliability in a pilot study. The device produced an intra-class correlation ($ICC_{3,1}$) = 0.996 and precision (SEM) =.000564. Specific gravity determines urine concentration and is defined as the ratio of the density of a given liquid to the density of water. Specific gravity levels less than or between 1.010-1.290

reflect a well hydrated condition, but a reading of more than 1.030 reflects dehydration (Casa et al., 2000). The device is less subjective than relying on urine color charts to determine hydration status. (Casa et al., 2000)

Before using the refractometer it must be calibrated to 1.000 at the start of each testing session. The device does not need to be calibrated between subjects, but it was cleaned between each individual use to make sure no cross contamination between samples occurred. The tip of the device, which is immersed in the urine sample, was cleaned with anti-bacterial soap and warm water. When collecting the urine specimen, the subjects need to provide 2-oz to 4-oz from the mainstream of urine excretion. The sample will be analyzed on site, the sample will be flushed into the plumbing system, and the cup will be cleaned, disinfected, and reused at a later date.

Protocols

Data Collection Days

Data collection occurred during the 2009 football season at the University of North Carolina at Chapel Hill which began on August 7th and ended November 28th. Data collection occurred on August 11th (session 1), 20th (session 2), 21st (session 3), and October 14th (Session 4/Control). The control session occurred in an environmentally controlled indoor facility which maintained the ambient temperature at an average of 72^{o}F and removed the affect the sun played in temperature factors. The coaching staff informed us which days during camp were going to be the most physically challenging, and we chose these days since more impacts would be recorded. August 11th, 20th, and October 14th were chosen because they were impact oriented practices and players would be in full pads. Data was collected on the morning of the 21st since eleven of the subjects retained the CorTemp pill from the pervious day's mid-afternoon practice.

Baseline

The subjects were recruited upon their return to campus for training camp. Before the start of training camp, each subject's height and mass was obtained as well as age, football position, and history of heat illness. Height measurements were taken using a stadiometer after the athletes' had removed their shoes. Mass was obtained with the athletes wearing compression shorts on a standing weight scale (Wildcat Scale, Mettler-Toledo Scale & System Ltd.; Toledo, OH). The undergarments the subjects wore are very light in weight and should not cause a discrepancy in the subject's mass.

The amount of fluid the subjects ingested was not monitored, and they were not given any specific directions pertaining to hydration for the purpose of this study. The subjects encountered normal encouragement to hydrate from their supervising athletic trainers, during the data collection days. We did not want to alter the subjects' normal routine and that is why we elected not to monitor or directly give guidelines for hydration.

Pre-Practice

Before the ingestible pill was consumed, the pill was activated. To activate the pill, the magnet adhered to the pill was removed to turn on the battery. To verify the sensor was working and the signal was being received, a sensor test was performed using the handheld recorder. Once the sensor was confirmed to be in working order, the warranty seal was removed, and the sensor was given to the subject for consumption with a glass of tepid water.

Before the start of each practice, subjects consumed the CorTemp pills at least 4-5 hours before practice to allow the pill time to enter the gastrointestinal tract. Once in the intestinal tract, the temperature readings are not influenced by consumed food or liquid. In some instances, the thermister carried over to the next practice and data was collected during more than one practice session. However, if the consumed thermister did not carryover, the athlete was not required to consume another pill until the next testing session. (Godek et al., 2006; Yeargin et al., 2006) Only one pill can be consumed at a time due to interference between ingestible thermister's radio frequencies. To be sure the pill had been defecated, the handheld recorder was used to search for the pill signal by being placed near the small of the back and two inches superior to the right and left iliac crest. This is the method recommended by the manufacturer for determining if the thermister had been defecated. Subjects were also encouraged to observe their stool for signs of the pill.

Approximately one hour before stepping on to the practice field, the athlete's core body temperature, urine specific gravity, and body mass was recorded. (Godek et al., 2006; Yeargin et al., 2006) Body mass was recorded in the same manner as baseline measures. The subjects were required to provide a 2 to 4-oz sample of mainstream urine to evaluate their urine specific gravity levels. (Patel et al., 2007)

Practice

During practice, the subjects' core body temperatures were recorded as they stepped through the entrance gate and on to the playing field. Temperature readings were obtained every 10-15 minutes, for the entirety of the practice. (Godek et al., 2006) Before the start of a cool down period, the subjects' core body temperature was obtained and at the end of the period before the subjects returned back to practice. The WBGT was recorded before the start of practice and in thirty minute increments throughout practice at the middle of the practice fields.

Subjects were allowed to participate normally during practice, during the data collection days. During individual drills, it was very easy to walk behind a subject, record their core body temperature, and leave without drawing their attention away from practice. During team drills, core body temperatures were recorded once a subject was finished with a series of plays and on the sideline where data could be obtained without interfering with practice.

Post-Practice

At the end of practice, core body temperature was recorded as the subjects left the field, and the WBGT was recorded in the same location as the previously mentioned readings. Before the subjects showered, their mass and urine specific gravity was recorded. While obtaining weight measurements, the subjects wore the same attire as previous measurements.

Data Reduction

Outcome measures were obtained from the CorTemp ingestible thermisters which yielded core body temperature readings that was taken from the database on a computer containing the software package and entered into a statistical software package. The raw impact data were exported from the Sideline Response System into Matlab 9.1(The Mathwarks, Inc., Natick, MA), where data were reduced to include only the four data collection days during the fall season and only impacts registering above 10g. The in-helmet temperature data is included with the exported impact information from the Sideline Response System. The WBGT and pre-post practice mass was recorded and stored in an Excel file and later imported into the statistical analysis software.

Statistical Analysis

To answer the first research question, three overall random intercepts general linear mixed models were employed for each of our dependent variables (resultant linear acceleration, resultant rotational acceleration, and the HITsp). Player represented one level in each statistical model as a repeated factor. Core body temperature, in-helmet temperature, WBGT, ambient temperature and dehydration served as independent variables of interest and were all included in the separate overall models. In order to further investigate our research question, separate random intercepts general linear mixed models were conducted with each dependent variable and one independent variable included in the model. A total of fifteen separate analyses were calculated in order to evaluate each independent variable to each dependent variable. This allowed us to analyze each independent variable without the other independent variables being controlled for in the model.

To answer our third research question, we analyzed our three training camp sessions compared to the fourth control session. This allowed us to determine impact differences between training camp sessions and the fourth control session. The fourth research question of determining if in-helmet temperature is a valid device for measuring core body temperature was answered by computing change scores between in-helmet temperature and core body temperature. To derive at the change score we subtracted the in-helmet temperature from core body temperature. After we computed the change score, the outcomes were used in a one-sample t-test with the test value set at zero. The fifth question assesses the relationships between our predictor variables (core body temperature vs. in-helmet temperature, core body temperature vs. ambient temperature, core body temperature vs. WBGT). A series of random intercepts general linear mixed models were utilized to determine the relationship between the variables. Table 1 provides the research questions and type of analysis conducted to answer our research questions. An alpha level of .05 was set prior to analysis and data was analyzed using SAS (SAS Institute, Inc.; Cary, NC).

CHAPTER IV

RESULTS

Eighteen football athletes were recruited to participate in this study. These athletes were representative of a larger sample of subjects participating in an ongoing clinical research initiative. Due to injury attrition, only 17 individuals participated in the second and third practice sessions during training camp. On the last day of data collection, only 15 of these subjects participated in the fourth data collection period. Overall, 1140 impacts were recorded over the 4 test periods. The offensive and defensive linemen accounted for 736 recorded head impacts. The defensive backs and wide receivers accounted for 187 head impacts, and the linebackers and running backs accounted for remaining 217 head impacts. Table 3 depicts the mean and standard deviations for the impacts recorded by each position group. The results of our study are presented in this chapter.

Linear Acceleration

In assessing linear acceleration, the random intercepts general linear mixed model tested each prediction variable (ambient temperature, core body temperature, dehydration, WBGT, and in-helmet temperature) while controlling for the remaining four variables not being tested. Ambient temperature ($F_{1,606} = 11.26$, $P < 0.01$) was the only statistically significant finding observed in the overall model. The equation produced from the overall random intercepts general linear mixed model (linear acceleration = 152.62 + 0.7651 * ambient temperature (C^{o}) + 0.1395 * WBGT (C^{o}) – 4.1838 * core temperature – 0.1811 * helmet temperature + 0.01042 * mass) is clinically impractical and meaningless. The four remaining prediction variables in the overall model, WBGT ($F_{1,606}$ = 2.01, P = 0.16), core body temperature ($F_{1,606}$ =2.45, P = 0.11), in-helmet temperature ($F_{1,606}$ = 0.82, P = 0.36), and dehydration ($F_{1,606}$ = 3.48, P = 0.06) were not significant predictors of linear acceleration. Results from our overall random intercepts general linear mixed model for linear acceleration can be found in Table 4.

In order to further explore these factors, we individually included the dependent variables in separate random intercepts general linear mixed models. When dehydration, core body temperature, in-helmet temperature, and WBGT were not controlled for ambient temperature did not significantly affect linear acceleration ($F_{1, 1119}$ = 1.90, P = 0.17). When analyzed independently, wet bulb globe temperature ($F_{1,1038}$ = 1.12, P = 0.29), core body temperature ($F_{1, 729}$ = 0.81, P = 0.37), in-helmet temperature ($F_{1, 1081}$ = 0.43, P = 0.51), and dehydration ($F_{1,992}$ = 0.49, P = 0.48) were not significant predictors of linear acceleration. Results from our linear acceleration statistical analyses are provided in Table 5.

Rotational Acceleration

In assessing rotational acceleration, the random intercepts general linear mixed model tested each prediction variable (ambient temperature, core body temperature, dehydration, WBGT, and in-helmet temperature) while controlling for the remaining four variables not being tested. Wet bulb globe temperature ($F_{1,606}$ = 11.95, P < 0.01) was the only statistically significant finding observed in the overall model. The equation produced from the overall random intercepts general linear mixed model (rotational acceleration = 2618.62 + 30.5638 * ambient temperature (C^o) + 21.1436 * WBGT (C^o) – 84.8146 * core temperature + 10.0579 * helmet temperature + 0.01042 * mass) is clinically impractical and meaningless. Ambient temperature ($F_{1,606}$ = 2.32, P = 0.13), core body temperature ($F_{1,606}$ = 0.15, P = 0.69), in-helmet temperature ($F_{1,606}$ = 0.33, *P* = 0.56), and dehydration ($F_{1,606}$ = 2.03, *P* = 0.16) were not significant predictors of rotational acceleration. Results from our overall random intercepts general linear mixed model for rotational acceleration can be found in Table 4.

In order to further explore these factors, we individually included the dependent variables in separate random intercepts general linear mixed models. No significant predictor was observed from the individual analysis: ambient temperature ($F_{1,1119}$ = 3.40, *P* = 0.07), WBGT ($F_{1,1038}$ = 0.57, *P* = 0.45) core body temperature ($F_{1,729}$ = 0.00, *P* = 0.98), in-helmet temperature ($F_{1,1081}$ = 1.76, *P* = 0.18) and dehydration ($F_{1,992}$ = 0.23, *P* = 0.63). Results from our rotational prediction analyses are provided in Table 5.

Head Impact Technology severity profile (HITsp)

In assessing HITsp, the random intercepts general linear mixed model tested each prediction variable (ambient temperature, core body temperature, dehydration, WBGT, and in-helmet temperature) while controlling for the remaining four variables not being tested. No statistical significance was observed for the following prediction variables in the overall model: ambient temperature ($F_{1,606}$ = 1.28, P = 0.26), WBGT ($F_{1,606}$ = 3.41, P = 0.06), core body temperature ($F_{1,606}$ = 1.15, P = 0.28), in-helmet temperature ($F_{1,606}$ = 0.99, P = 0.32), and dehydration ($F_{1, 606}$ = 2.29, P = 0.13). Results from our overall random intercepts general linear mixed model for HITsp can be found in Table 4.

In order to further explore these factors, we individually included the dependent variables in separate random intercepts general linear mixed models. A single statistically significant predictor was observed for HITsp. The significant predictor was in-helmet temperature ($F_{1, 1081}$ = 3.74, P = 0.05). The four remaining predictor variables, ambient temperature ($F_{1, 1119}$ = 2.35, P = 0.13), WBGT ($F_{1, 1038}$ = 0.02, P = 0.89), core body temperature ($F_{1, 729}$ = 0.55, P = 0.46), and dehydration ($F_{1,992}$ = 1.65, P =0.19) were not statistical predictors of HITsp. Results from our HITsp prediction analyses are provided in Table 5**.**

Session Comparisons

In order to analyze whether session differences existed, seperature random intercepts general linear mixed models were employed for each dependent variables (linear acceleration, rotational acceleration, and HITsp) comparing the first three sessions (training camp) to the fourth (control) session. Not one of our impact magnitude variables from the training camp sessions was statistically different from the control session in the overall model: linear acceleration ($F_{3,44}$ = 0.68, P = 0.57), rotational acceleration ($F_{3,44}$ = 1.80, P = 0.16), and HITsp ($F_{3,44}$ = 1.18, P = 0.33). Table 6 depicts the recorded impacts for each session and the comparison between the mean resultant linear acceleration, rotational acceleration, and HITsp of head impacts sustained during the practice sessions.

We investigated if a statistical difference would exist when session 2 was used as the control session and the remaining three sessions were compared to the control. The random intercepts general linear mixed model employed found no significant interaction between the sessions: linear acceleration ($F_{3,44}$ = 0.68, P = 0.57), rotational acceleration ($F_{3,44}$ = 1.80, P = 0.16), and HITsp ($F_{3,44}$ = 1.18, P = 0.33). Table 7 depicts the recorded impacts for each session and the comparison between the mean resultant linear acceleration, rotational acceleration, and HITsp of head impacts sustained during the practice sessions.

Additional Analysis

To account for subject attrition, the date comparison random intercepts general linear mixed models were calculated with the three subjects removed who could not complete all testing days. Overall, the model was still not significantly different from the initial analysis. Table 8 depicts the statistical output from this analysis.

Validity of In-Helmet Thermister

We computed change scores by subtracting the in-helmet temperature from core body temperature. Theoretically, subtracting in-helmet temperature from core temperature would yield values close to zero if the in-helmet thermister were truly representative of core body temperature. Therefore, we compared this change score against a test value of zero using a one-sample t-test. A significant difference was found ($t_{715} = -37.07$, $P < 0.01$). The change score observed (mean = -6.25; sd = 4.51) suggested the in-helmet thermister significantly underestimated core body temperature. Figures 5-8 depict the comparison of core body temperature averages to the in-helmet temperature averages during the four data collection days.

Relationships between Different Temperature Measures

Random intercepts general linear mixed models were also used to analyze the relationship between core body temperature and our other temperature variables. The statistical results are described below and are detailed in Table 9.

Core Body Temperature vs. In-Helmet Temperature

A significant relationship was found between core body temperature and in-helmet temperature ($F_{1,697} = 5.38$, $P = 0.02$). Though statistically significant, the estimate equation produced by the random intercepts general linear mixed model, core temperature = .01622 * helmet temperature + 37.7999, is a very poor estimation of core body temperature for clinical proposes.

Core Body Temperature vs. Ambient Temperature

A significant relationship was found between core body temperature and ambient temperature ($F_{1,729} = 12.57$, $P < 0.01$). Though statistically significant, the estimate equation drawn from the random intercepts general linear mixed model, core body temperature = 0.02213 * ambient temperature + 37.6099, is a very poor estimation of core body temperature for clinical proposes.

Core body Temperature vs. Wet Bulb Globe Temperature

A significant relationship was found between core body temperature and WBGT ($F_{1,689} = 7.79$, $P < 0.01$). Though statistically significant, the estimate equation drawn from the random intercepts general linear mixed model, core body temperature = -0.01525 * WBGT + 38.5040, is a very poor estimation of core body temperature for clinical proposes.

CHAPTER V

DISCUSSION

The purpose of this study was to determine the effect dehydration, ambient temperature, core body temperature, WBGT, and in-helmet temperature have on impact magnitudes. Our hypothesis that these variables would be very strong predictors of impact magnitude was rejected. The results provided statistically different interactions, but only one of the significant findings was clinically relevant. The results suggest none of the overall models were significant predictors of impact magnitude. Out of all of the variables, in-helmet temperature was the only individual variable that was a statistically significant predictor of impact magnitude; however, in-helmet temperature only influenced HITsp. The statistical interaction lacks clinical significance, because it does not provide clinicians with a method to accurately estimate how impact magnitudes are altered by environmental conditions. Clinically, the most important finding of our study is the in-helmet thermister is not a valid device for measuring core body temperature.

To our knowledge, this study is the first to investigate how environmental and physiological conditions affect impact magnitude during fall football practice. These questions are of particular interest to clinicians who are tasked with the prevention and care of athletic injuries. Previous studies have investigated the biomechanical differences in football, but none of these studies have looked at environmental conditions, core body temperature, or dehydration factors that might influence impact magnitudes. (Broglio et al., 2009; Guskiewicz & Mihalik, 2007; McCaffrey et al., 2007; Mihalik et al., 2007)

Ambient Temperature

Ambient temperature did not affect linear acceleration. The overall model, which provided an estimate equation, was statistically insignificant. The fact that linear acceleration was not statistically different between our three experimental sessions held during high-heat conditions in preseason camp, and the control session held in a climate-controlled indoor facility midway through the regular season was interesting. The lower ambient temperature (72.4^{o}F) of the control session did not result in lower linear accelerations when compared to the hottest pre-season training camp session (100.3^{o}F). The results suggest ambient temperature in itself played no role in affecting linear acceleration; however, rotational acceleration was approaching significance between session 1 and session 4, and session 2 compared to session 4. The practice sessions were similar with respect to the within-practice drill schedule: any differences in rotational acceleration observed is not likely attributable to the effect of practice differences. The statistical information indicates the difference cannot be attributed to WBGT. It is apparent that as ambient temperature decreased the mean rotational acceleration decreased, but the difference may be due to player improvement with tackling technique as the season progressed. Obviously, these findings need to be confirmed in studies involving more sessions, which would provide more information to determine if this trend would be consistently noticed; however, they do provide a basic understanding into how ambient temperature may play a role in rotational accelerations. If proven, these findings would indicate rotational acceleration is influenced by ambient temperature and could possibly be a contributory factor as to why clinicians seem to encounter more concussions during the hotter days of the summer as compared to the cooler days of the season.

Wet Bulb Globe Temperature

Wet bulb globe temperature had no influence on impact magnitude. Wet bulb globe temperature is a useful means to monitor environmental conditions, but this study suggests it is not appropriate to use WBGT as a predictor of impact magnitudes. Clinicians should continue to utilize WBGT measures to analyze environmental conditions. These measures provide objective information to alter practice. (Cooper et al., 2006; Coris et al., 2004)

In-Helmet Temperature

The in-helmet thermister that is housed in all HIT System accelerometers is not a valid device for measuring core body temperature. Clinicians should never us the device for interpreting a player's core body temperature. The in-helmet thermister reported temperatures lower than core body temperature readings during the four data collection days. Figures 5-8 provide a comparison of in-helmet temperature and core body temperature. The in-helmet temperature was consistently below core body temperature, but also it did not follow the same trend as core body temperature. Core body temperature readings gradually increased as practice progressed and the gradual increase is expected; however, the in-helmet temperature did not follow the same trend line as core body temperature. The in-helmet temperature readings were sporadic and seem to be influenced more by ambient temperature rather than core body temperature.

The difference between session 1 and session 3 illustrates how in-helmet temperature seemed to be influenced by ambient temperature rather than core body temperature (Figure 5 & 8). At the beginning of session 1, the lower in-helmet temperature readings could be attributed to players just beginning to wear their helmets. When the helmets are not being worn they are not in direct sunlight and may not be influenced by radiant energy, but once the helmets are being worn they are directly exposed to direct sunlight. At the middle third of practice, during individual drills when the majority of the athletes were wearing their helmets, the in-helmet temperature increased to a point in which it closely resembled ambient temperature. The in-helmet temperature was still below core body temperature readings during the middle third of practice. The decline of in-helmet temperature over the last 30 minutes of session 1 can be attributed to players removing their helmets. At the end of each practice, the team practices as a unit and during this time more individuals have the opportunity to remove their helmets and cool down. This trend is noticed across all four sessions, and once the helmet is removed from direct sunlight the temperature readings begin to decrease.

Session 3 was an early morning practice that began at 8:30, and the same in-helmet temperature trend that was noticed in session 1 was noticed in session 3. At the beginning of the practice, the in-helmet temperature average gradually increased during the first 30 minutes of practice as the helmets encountered more direct exposure to environmental conditions, but once in the middle third of practice the average in-helmet temperature reached a stable line for the majority of the practice. At the end of the session 3, just like in session 1, when team drills began, the in-helmet temperature began to decline. Throughout session 3, the average in-helmet temperature readings were well below the average core body temperature readings.

Our suggestion that in-helmet temperature recording devices are not valid for measuring core body temperature is supported through work performed by Casa et al. who compared the reliability of temporal and forehead devices to rectal temperature assessment. The HIT system thermister is similar to these two methods of measuring temperature in the fact that the measures are recorded from the surface temperature of the head. The inaccuracies of the temporal and forehead devices were similar to our in-helmet thermister. (Casa et al., 2007; Ganio et al., 2009) In Casa et al.'s study, the temporal monitor consistently recorded temperatures lower than rectal temperature, and the forehead device recorded readings above and below the rectal temperature.

We would like to emphasize that Riddell has never made a claim that the HIT System accelerometer units (more specifically the in-helmet thermisters built into these devices) should be used as a valid device for measuring core body temperature; however, other manufacturers have developed similar technology (in-helmet temperature measurement devices) and marketed them as a reliable means of measuring core body temperature. We strongly urge clinicians using in-helmet and skin surface devices that claim to measure core body temperature to exercise *extreme caution.* These devices have been shown to be unreliable and will provide inaccurate information when assessing core body temperature. (Casa et al., 2007)

The inaccuracy of these devices to measure core body temperature can be attributed to a multitude of things like removing helmets when not involved with practice, athletes' cooling their heads with cool water or cold towels, or the difference in helmet design. Helmets like the Riddell Revolution or Riddell Speed have holes along the superior aspect of the helmet so heat can escape, but the Riddell VSR-4 does not have these holes on the superior aspect. The only method of heat loss in the VSR-4 is through the ear holes. Clinicians should use caution and rely on research when considering new products for core body temperature assessment.

In-helmet temperature statistically influenced HITsp, but the estimate equation (HITsp = 0.1873 * in-helmet temperature + 8.3163) is clinically meaningless. In-helmet temperature was the only variable that was an individual predictor of impact magnitude. The fact none of the other variables individually predicted impact magnitude is very peculiar, because there was a statistical relationship noted between in-helmet temperature and ambient temperature. Since in-helmet temperature was related to ambient temperature, this variable should have been a statistical predictor of HITsp as well. The fact ambient temperature is not a statistical predictor is alarming and suggests in-helmet temperature was not a true statistical predictor but a statistical coincidence.

Dehydration

Dehydration did not affect impact magnitude in our study; however, our methods of measuring dehydration were limited to pre-post practice mass differences. The average percent mass loss due to sweating during practice for the entire cohort during the four data collection days was 1.3%. Two percent or greater of total mass loss is classified as dehydrated and has been described as the amount of fluid loss for physiological and performance impairments to occur. (Casa et al., 2000) Out of 67 exposures, there were only 10 instances where subjects weighed in post-practice with a mass percent loss greater than 2%. The low number of subjects who lost more than 2% of their mass can be attributed to the clinical practice employed by the team's athletic trainers in ensuring that athletes remain properly hydrated throughout heat-intensive practices.

During the training camp sessions, the entire football team from which our subjects were recruited was provided with more than sufficient chances to maintain hydration. Rest periods normally lasted five minutes and occurred under large tents with moist cool fans underneath providing circulation. The rest periods allowed athletes an opportunity to cool down and replenish fluids. Sport drinks, cold towels, and water were provided during each break and throughout the practice as needed. Unfortunately, not all athletic departments have the means to provide unlimited access to sports drinks or have a tent with circulating fans for practice, but incorporating any type of rest opportunity is essential when practicing during unfavorable environmental conditions.

Beyond the implementation of rest periods, the coaching staff designed their practices to get the most out of the team. The practices are designed with a warm-up period followed by periods where the intensity gradually increases. On hotter days, a rest period was incorporated into the schedule after one to two rigorous periods. The period following the break is less demanding, and allows for the gradual increase in intensity to start over. The last few periods of practice are challenging and push the athletes to increase their endurance. The roller coaster practice schedule coupled with the periodic rest period clinically kept the number of dehydrated individuals to a minimum.

If dehydration would have been more prevalent during the practice sessions, impact magnitudes might have been altered. The physiological events that occur to keep the body in a homeostatic state while dehydrated did not influence recorded impact magnitudes in this study. Research has determined that dehydration results in a decrease in performance. Work performance can decrease 18-44 percent during two percent and four percent dehydrated test trials when compared to hydrated trials (Craig & Cummings, 1966); however, dehydration has little effect on single maximal effort strength and power test, but it limits the muscular endurance of trained athletes. (Judelson et al., 2007) It was assumed that as athletes became more dehydrated, the severity of impact magnitude would increase due to a decrease in performance and ability to defend themselves from oncoming collisions. These findings suggest that dehydration does not play a role in impact magnitude; however, additional studies need to be conducted with a larger sample of individuals who meet the dehydration criteria.

Core Body Temperature

Core body temperature had no influence on impact magnitude. According to the literature, as core body temperature elevates, there is a decrease in cerebral blood flow due to the shunting of blood to the periphery in attempts to cool the body. (Nielsen & Nybo, 2003) Measurement of cerebral blood flow is limited to laboratories and cannot be obtained during football practice. The premise of this study was based on the notion that as a player's core body temperature increased, there would be a resultant decrease in the amount of cerebral blood in the cranium. The decrease of fluid in the brain would result in a decreased inability to absorb impacts and would result in greater impact magnitudes; however, core body temperature did not affect impact magnitude and does not contribute to changes in impact magnitudes.

It is important to note the HIT system has been validated in laboratory studies to measure head acceleration and not helmet acceleration. (Manoogian et al., 2006) Head acceleration is of interest when dealing with a decrease of fluid within the cranium; however, no known study has determined if decreases in intracranial fluid affects impact magnitude. Our study was a very basic attempt to determine if the physiological effects of an elevated core body temperature would affect impact magnitude. Research in a laboratory setting should be conducted in order to determine if elevated core body temperatures affect impact magnitudes due to the decrease of blood volume within the cranium.

Limitations

This study was limited by the number of sessions that could be used to gather data. The four data collection days were based on the fact they would be the most demanding and contact oriented practices. Including more session days into the study would have provided a better understanding of how differing environmental conditions might have affected impact magnitudes.

Our study did not investigate concussive episodes. All of the subjects were healthy individuals who did not suffer a concussive episode during the data collection days. More injuries need to be recorded and analyzed to have a better understanding about the notion that more concussive episodes occur during the hotter climate days than cooler days. We were unable to contribute any useful information to this notion since no injury was reported during data collection.

During the study only 10 individuals were considered dehydrated due to their amount of mass loss. The subjects were not on any type of fluid restriction during data collection days. The risk of inducing dehydration then participating in football practice is dangerous and not ethical. Not knowing the exact hydration status of our subjects throughout practice limited us from making precise associations with recorded impact magnitudes. In order to associate hydration status to impact magnitude, the pre-practice mass was related to the beginning third of practice, the average between the pre-post practice mass to the middle third of practice, and post-practice mass to the final third of practice.

Environmental conditions could not be recorded on a constant basis. The conditions were recorded in 15-minute increments throughout practice. If impacts were recorded between the 15-minute increments, the average of the two environmental readings was associated with the recorded impacts. Ideally, if environmental conditions were recorded consistently, then exact environmental temperatures could be associated with the impact magnitudes.

Conclusions

Our study suggests that physiological and environmental conditions do not affect impact magnitudes. No significant predictor was noticed or combination of predictors for impact magnitude was identified through our study. We recommend that clinicians use caution when investigating new products to measure core body temperature. The in-helmet thermister proved to be invalid, and before investing in a product be positive that it has been proven valid and reliable for measuring core body temperature.

Future investigations should utilize a broader spectrum of environmental conditions. The difference between regions should be taken into account. The conditions encountered in North Carolina are different than conditions that would be encountered in other regions of the country.

Future, studies should also investigate how different practice regimens between teams influence impact magnitudes. Different coaching staffs have different philosophies when it comes to practice schedules. Some coaches believe consistent hard hitting practices are necessary. While other coaches take a less invasive approach to practice. Investigations need to be conducted to develop a practice guideline for coaches to follow that result in less impact during practices.

Muscle fatigue is another area of investigation that needs to be explored. Dehydration has been shown to decrease muscular endurance, but it is not known how dehydration could affect neck muscular endurance. Neck muscular fatigue may play a role in increased impact magnitudes since the athlete is unable to optimally guard themselves from an oncoming impact.

Just like protocols have been established to help reduce dehydration and exertional heat illnesses in unfavorable conditions, research must continue to investigate how impact magnitudes can be influenced by external factors. If factors are found that influence impact magnitudes, clinicians might be able to account for these factors and potentially decrease the amount of unnecessary impacts.

APPENDIX A

Informed Consent

University of North Carolina-Chapel Hill
Consent to Participate in a Research Study
Adult Subjects
Biomedical Form

IRB Study #____09-1385__________________
Consent Form Version Date: ______7/31/2009________
Title of Study: Dehydration, Core Body, Wet Bulb Globe, and in Helmet Temperature are Predictors of Impact Magnitude

Principal Investigator: Adam Z. Sumrall, MA, ATC
UNC-Chapel Hill Department: Exercise and Sport Science
UNC-Chapel Hill Phone number: 919-843-2014
Email Address: sumrall@email.unc.edu
Co-Investigators: Jason P. Mihalik, MS, CAT(C), ATC; Edgar W. Shields, PhD; Scott Trulock, MA, ATC; Kevin King, MA, ATC
Faculty Advisor: Kevin M. Guskiewicz, PhD, ATC
Funding Source and/or Sponsor: N/A

Study Contact telephone number: 919.843.2014
Study Contact email: jmihalik@email.unc.edu

What are some general things you should know about research studies?
You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?

The purpose of this study is to learn about the effects of dehydration, core body temperature, wet bulb globe temperature (ambient temperature), and in helmet temperature on head impact magnitude sustained in football athletes during regular participation. We are trying to determine if athletes sustain greater forces to the head if they are dehydrated, their core body temperature is elevated, or if unfavorable outside environmental conditions influence impact magnitude. You are being asked to participate in the study because you are a Division I collegiate football athlete at the University of North Carolina at Chapel Hill between the ages of 18-24 years who has already consented to participate in another study that has provided you with helmet sensors (IRB#04-1194).

Are there any reasons you should not be in this study?

You should not be in this study if you have any known gastrointestinal tract disease, impairment or disorders of the gag reflex, or have had any previous gastrointestinal surgery. If you are currently dealing with any form of spinal cord, brain or other neurotramatic injury you should not include yourself in this study.

1. Do you have a presence or history of gastrointestinal tract disease? Yes/No
2. Do you have impairment or a disorder of the gag reflex? Yes/No
3. Do you have a previous history of gastrointestinal surgery? Yes/No
4. Are you suffering from spinal cord, brain or other neurotramatic injury? Yes/No

How many people will take part in this study?

If you decide to be in this study, you will be one of approximately 15 people in this research study.

How long will your part in this study last?

You will be involved with this study for four sessions during the 2009 football season. The planned dates for data collection consist of the first and last days of two-a-day practices during fall training camp (August 2009), and two additional sessions in mid-October and mid-November. Each day we will require you to report to the Kenan Stadium athletic training room three hours before practice to receive and consume one ingestible core temperature pill. One hour before you leave for the practice field, we will record your body weight and urine specific gravity. These two procedures will take approximately 10 minutes. Once back in the locker room after practice, we will measure your body weight and urine specific gravity again. You will not be required to perform anything further outside of these sessions.

<u>What will happen if you take part in the study?</u>
If you agree to participate in this research study, we will ask that you complete the following requirements:

Baseline:

- We will record your age and body weight before the start of training camp.

Pre-Practice:

- Three hours before the start of each practice you will be required to consume the core temperature pill.
- One hour before the start of practice, we will measure your body weight and analyze your urine specific gravity.

Practice:

- During practice your core body temperature will be recorded as you step through the entrance gate and on to the playing field.
- Temperature readings will be obtained every 15 minutes, for the entirety of the practice.
- Before the start of any cool down period your core body temperature will be measured and before you return to practice it will be measured again.

Post-Practice:

- At the end of practice, your core body temperature will be recorded as you leave the field.
- Once in the locker room, weight measurements will be recorded along with analyzing your urine specific gravity levels.

No follow-up appointments or any other testing procedures are required of you outside of the data collection days.

- ***For Specimens**:*

  Urine samples will be collected in a specimen cup and will not be stored for later analysis. The sample will be evaluated at the time of collection and will be discarded once analysis is complete.

<u>What are the possible benefits from being in this study?</u>
Research is designed to benefit society by gaining new knowledge. There is little chance you will benefit from being in this research study.

<u>What are the possible risks or discomforts involved with being in this study?</u>
There are no immediate or long-term physical, psychological, and social risks related to the research components. However, the sport of football is high impact in nature and injuries occur due to sport participation. The procedures we are utilizing will not place you at an increased risk of suffering an injury.

<u>What if we learn about new findings or information during the study?</u>
You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

How will your privacy be protected?

Records will be stored on a laptop in the sports medicine research facility that is accessible only by password. The only individuals who will have access to the identifiable data will be the principle investigator and the faculty advisors. Since you are part of an ongoing study, you have been previously assigned identification numbers to distinguish your information. The previously assigned number will be used to identify your information. Your name, social security number, or any other form of personal identification will not be used in this study.

No subjects will be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

What will happen if you are injured by this research?

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

What if you want to stop before your part in the study is complete?

You can withdraw from this study at any time without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected injury, or have failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study?

You will not receive anything for taking part in this study. Research allows us as a society to grow and build upon facts that we already know. By participating in this study, you are helping the growth of our society.

Will it cost you anything to be in this study?

It will not cost you anything to be in this study. All tests, visits or procedures other than what is done for this study will be related to medical care that is part of the usual care for your condition and would be suggested even if you decided not to be in the research study.

What if you are a UNC student?

You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you have questions about this study?
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research subject?
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

- -

Title of Study: Dehydration, Core Body, Wet Bulb Globe, and in Helmet Temperature are Predictors of Impact Magnitude

Principal Investigator: Adam Z. Sumrall, MA, ATC

Subject's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

____ _______________
Signature of Research Subject Date

____
Printed Name of Research Subject

____ _______________
Signature of Research Team Member Obtaining Consent Date

____
Printed Name of Research Team Member Obtaining Consent

APPENDIX B

Figures

Figure 1: Accelerometer that fits into the Riddell Helmets with battery pack exposed.

Figure 2: Sideline control unit that stores and displays the information collected. Along side the control is the accelerometer unit and a Riddell helmet which the accelerometer fits into.

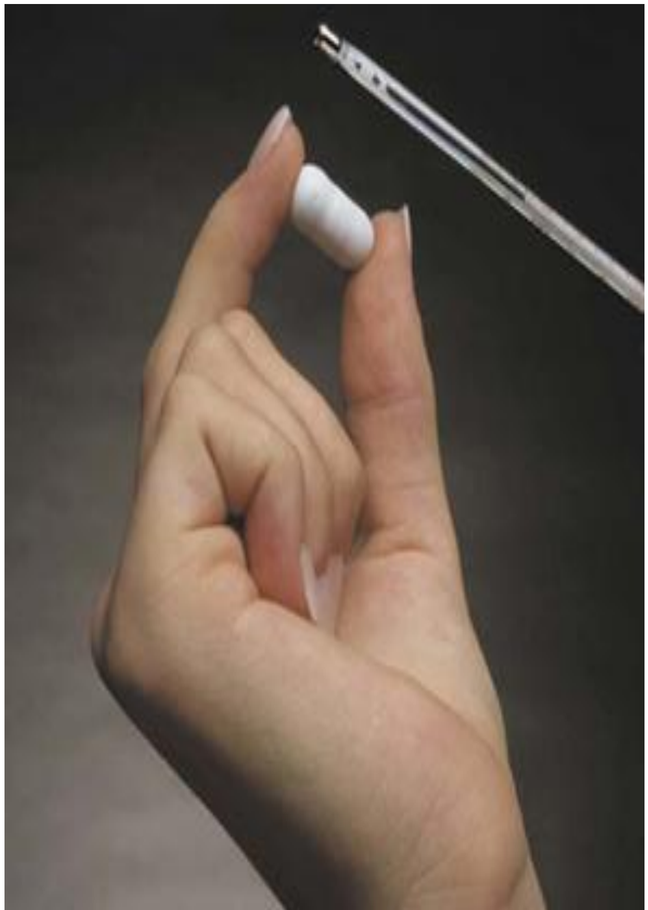

Figure 3: The CorTemp^{TM} ingestible core temperature pill which passes through the digestive tract.

Figure 4: CorTemp^{TM} Ingestible Core Body Temperature System which records core body temperature in real time. On the left is the data recorder and on the right is the ingestible thermister.

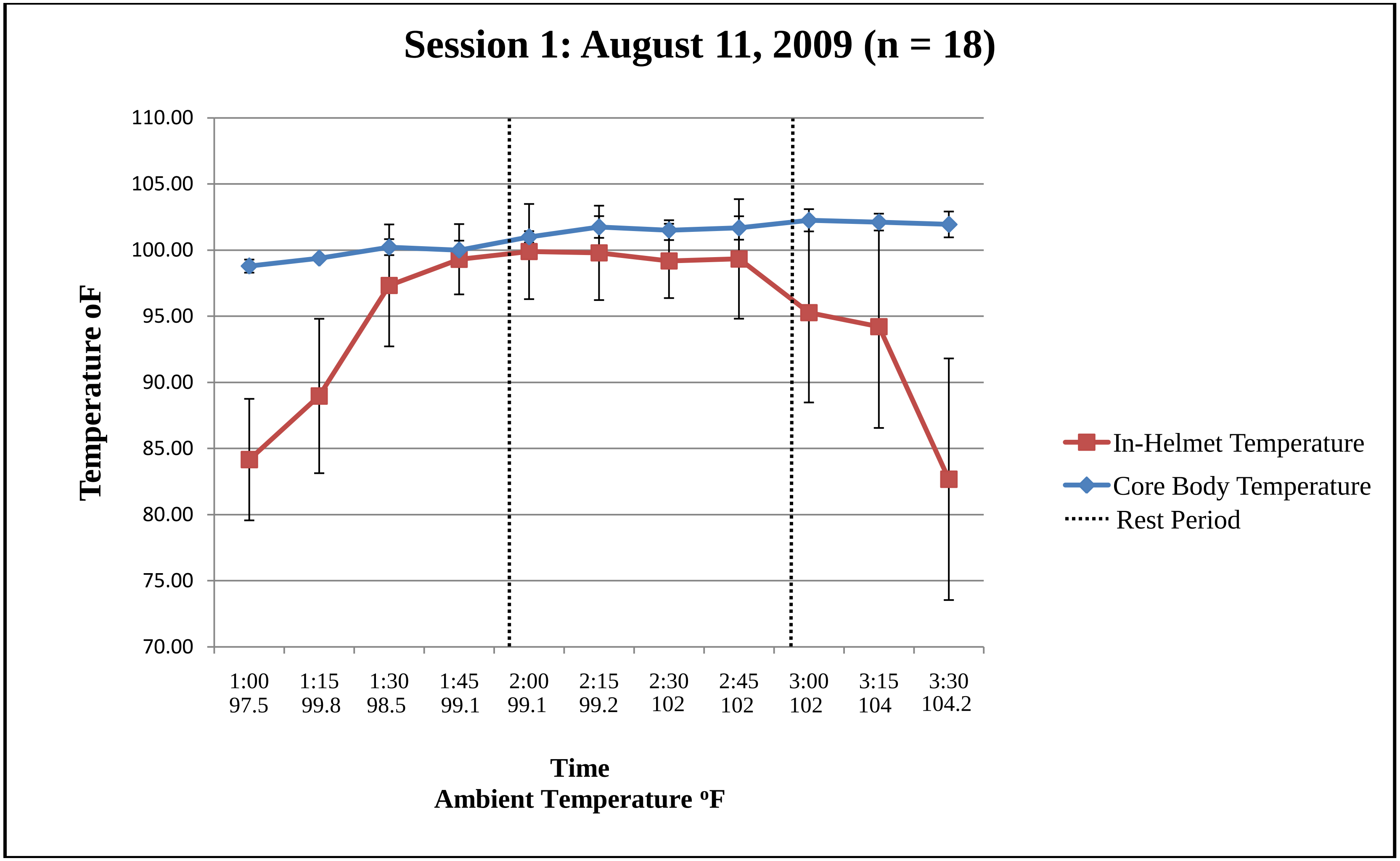

Figure 5: The average (SD) in-helmet temperature and average (SD) core body temperature compared to each other at 15 minute increments during session 1.

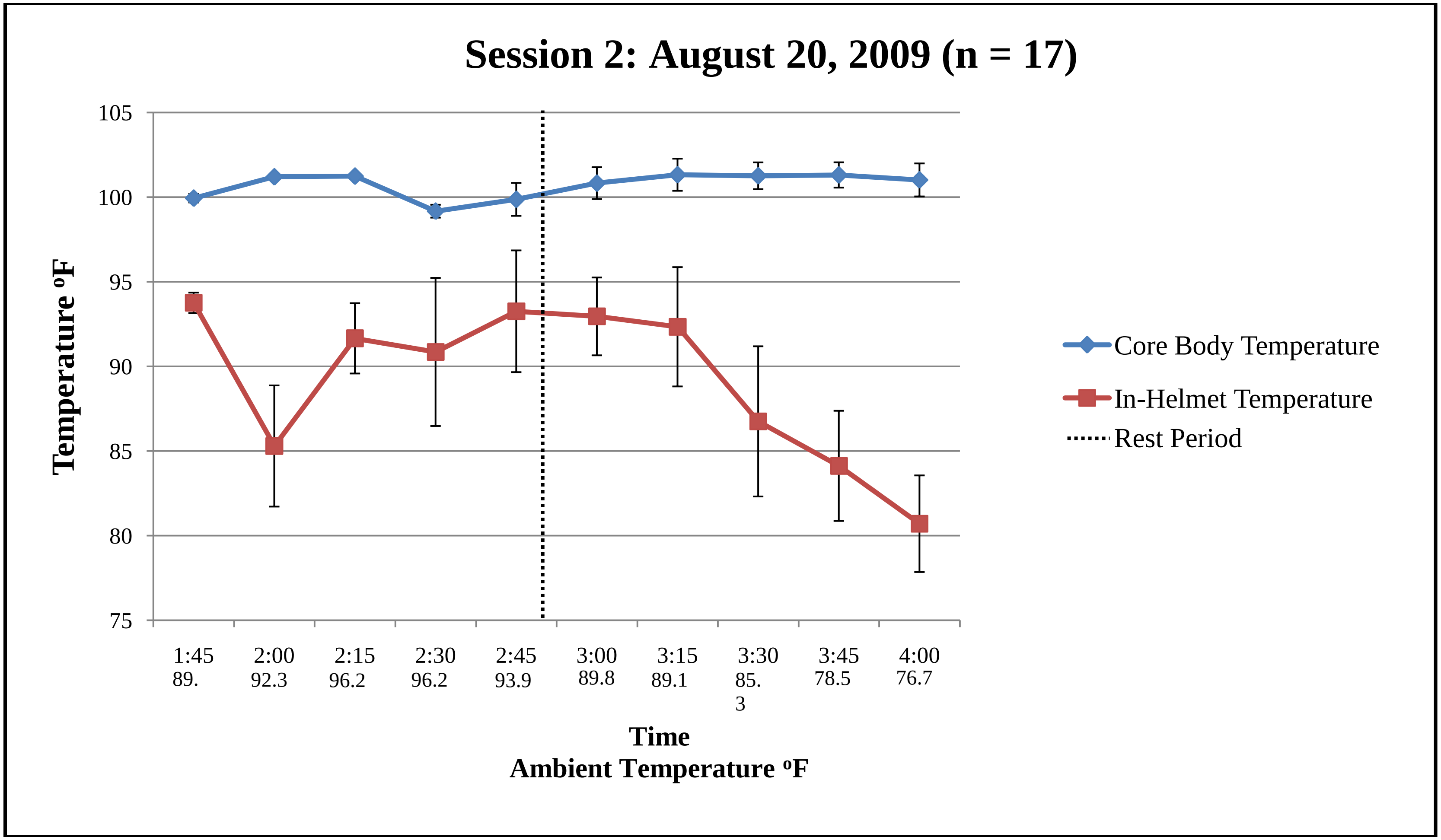

Figure 6: The average (SD) in-helmet temperature and average (SD) core body temperature compared to each other at 15 minute increments during session 2.

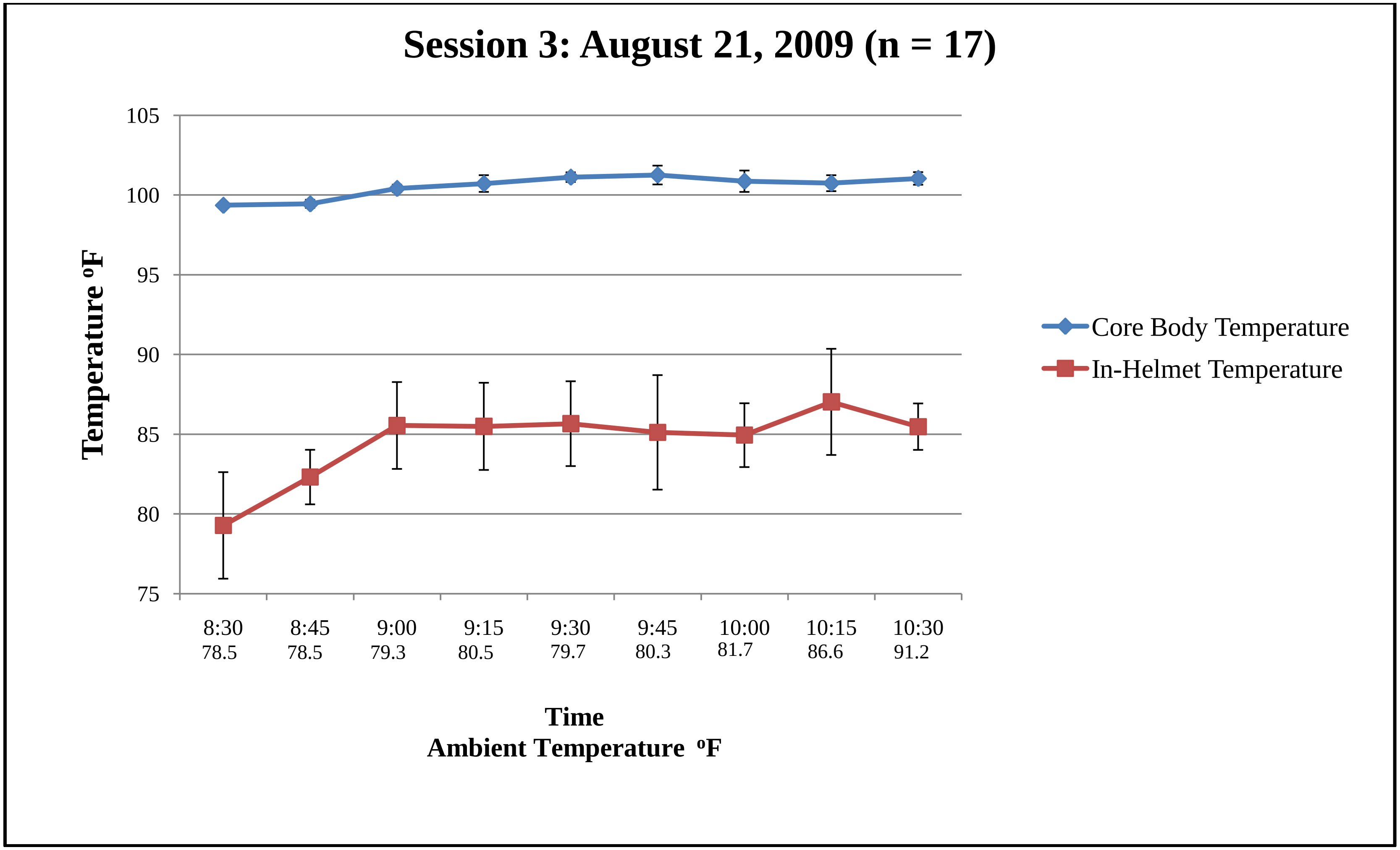

Figure 7: The average (SD) in-helmet temperature and average (SD) core body temperature compared to each other at 15 minute increments during session 3.

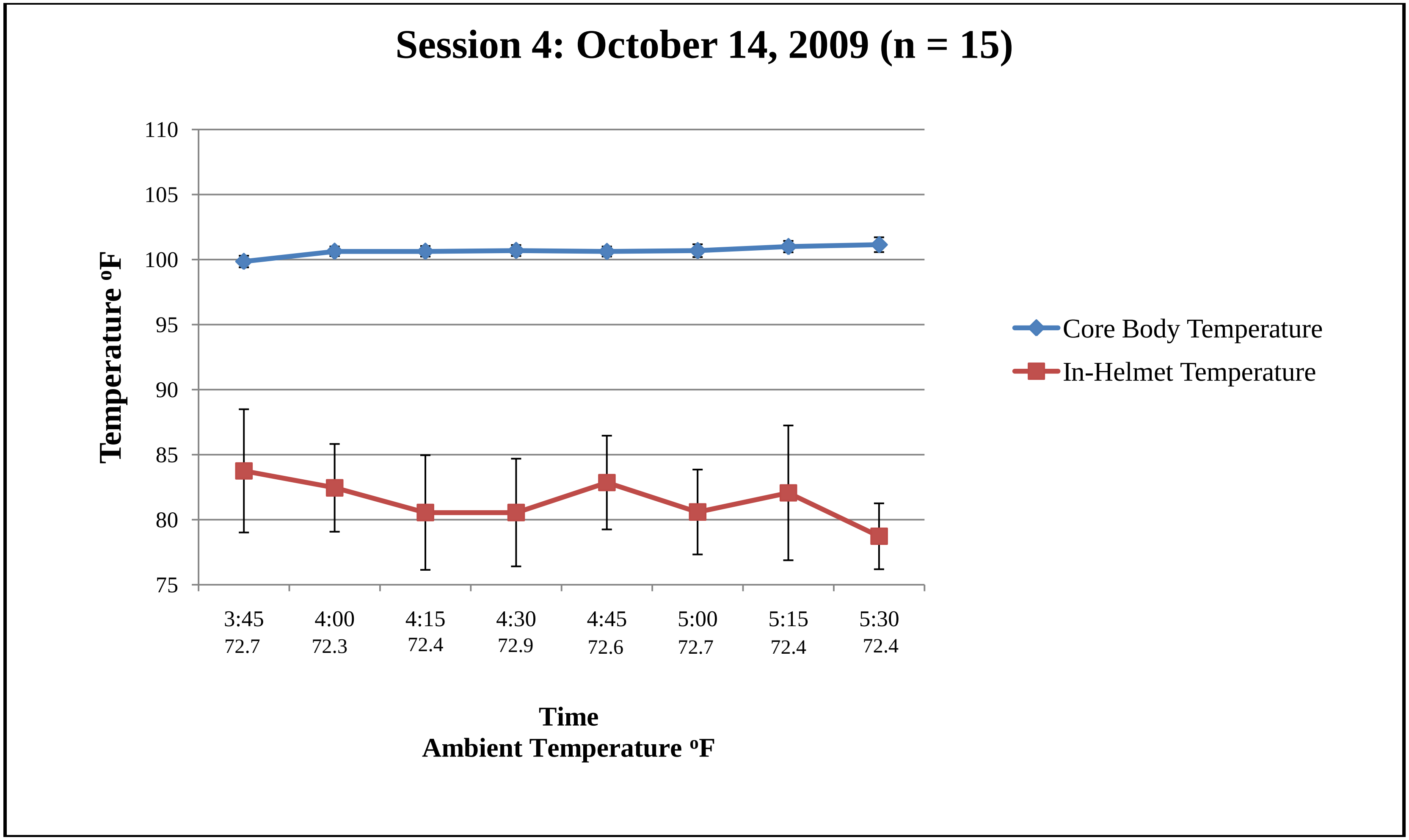

Figure 8: The average (SD) in-helmet temperature and average (SD) core body temperature compared to each other at 15 minute increments during session 4.

APPENDIX C

Testing Schedule

August 2009						
SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
				6 Players report to T.C.	7 PM – Practice #1 (shorts)	8 PM – Practice #2 (shorts)
9 PM – Practice #3 (1/2 pad)	10 PM – Practice #4 (1/2 pad)	11 PM- Data Collection Practice	12 AM – Practice #6 (Shells) EVE – Practice #7 (Pads)	13 PM – Practice #8 (Pads)	14 EVE – Practice #10 (Pads)	15 PM – Practice #11 (Pads) (Scrimmage)
16 AM – OFF PM – Lift 4	17 AM – Practice #12 (Shells) EVE – Practice #13 (Pads)	18 PM – Practice #14 (Pads) EVE – MTG #15	19 AM – Practice #15 (Shells) Eve – Practice #16 (Pads)	20 AM – MTG #17 Lift 6 PM – Data Collection Practice	21 AM – Data Collection Practice EVE – Practice #19 (Shells)	22 AM – Practice #20 (Pads) (Scrimmage)
23 Chapel AM – OFF PM – OFF	24 PM – Practice #21	25	26 Practice #22 (3:30) (Scrimmage)	27 Practice #23 (3:30)	28 Practice #24 (3:30)	29 PM/EVE – Practice #25
30 AM – OFF PM – MTG 26A (4:00)	31 OFF	1 Practice #26 (3:30)	2 Practice #27 (3:30)	3 Practice #28 (3:30)	4 Practice #29 (3:30)	5 CITADEL 6:00pm

October 2009						
SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
				1	2	3 @ Georgia Tech
4	5	6	7	8	9	10 Georgia Southern
11	12	13 JV Scrimmage	14 Data Collection Practice (Control)	15 PM Practice	16 PM Practice	17 Open Date
18 PM Practice	19 PM Practice	20 PM Practice	21 Walk Trough	22 Florida State	23	24
25	26	27	28	29 @ Virginia Tech	30	31

Appendix D

Tables

Table 1: Sample Description

Position	Age (years)		Height (cm)		Mass (kg)	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
OL/DL	21.4	1.6	192.3	4.5	136.9	14.2
RB/LB	21	1.8	182.9	4.2	104.6	6.4
WR/DB	21	1.4	184.6	6.6	91.3	4.9
Total	21.1	1.4	187.7	6.6	114.5	23.4

Note: OL: Offensive lineman; DL: Defensive lineman; RB: Running back; LB: Linebacker; WR: Wide Receiver; DB: Defensive back

Table 2: Statistical Analysis Chart

Question	Description	Data Source	Comparisons	Method
1	Do dehydration, core body temperature, WBGT, and in-helmet temperature predict impact magnitude across four test days during the fall season?	Predictors: Core Body Temperature, WBGT, and In-Helmet Temperature Criterion: Linear, Rotational, and HITsp	Dehydration, core body temperature, WBGT, and HIT system temperature compared to linear and rotational head accelerations and HITsp	Random Intercepts General Linear Mixed Models
2	Do dehydration, core body temperature, WBGT, and in-helmet temperature individually predict impact magnitude across four test days during the fall season?	Predictors: Core Body Temperature, WBGT, and In-Helmet Temperature Criterion: Linear, Rotational, and HITsp	Dehydration, core body temperature, WBGT, and HIT system temperature individually compared to linear and rotational head accelerations and HITsp	Random Intercepts General Linear Mixed Models
3	Do our three training camp sessions differ in impact magnitude when compared to the control session?	Dependent Variable: Impact Magnitude Independent Variable: Session	Each of the first three sessions compared to the fourth control session	Random Intercepts General Linear Mixed Models
4	Is the HIT system thermister a valid device for measuring core body temperature?	Core body temperature measures and in- helmet temperature	Computed a change score between in-helmet temperature minus core body temperature and compared result to test value zero.	One Sample T-test
5	What is the relationship between: - Core body and in-helmet temperature? - Core body and ambient temperature? - Core body and WBGT?	Core Body Temperature, WBGT, Ambient Temperature, and In-Helmet Temperature	Core body to in-helmet temperature. Core body to ambient temperature. Core body to WBGT.	Random Intercepts General Linear Mixed Models

Table 3: Mean (95% CI) for linear and rotational acceleration and HITsp for each position group from the four data collection days.

			Linear Acceleration (g)			Rotational Acceleration (rad/s^2)			HITsp		
Position Groups	**N**	**Impacts Recorded**	**Mean**	**95% CI**		**Mean**	**95% CI**		**Mean**	**95% CI**	
				L	**U**		**L**	**U**		**L**	**U**
OL/DL	8	736	24.5	23.3	25.7	1537.7	1445.8	1629.5	14.4	13.7	14.9
DB/WR	6	187	24.4	22.0	26.9	1557.5	1419.9	1727.6	13.4	12.6	14.8
LB/RB	4	217	26.7	24.0	29.4	1666.9	1468.3	1865.5	14.7	13.4	16.1
Total	18	1140	24.9	23.9	25.9	1568.8	1494.6	16.43.1	14.3	13.8	14.8

Note: OL: Offensive lineman; DL: Defensive lineman; RB: Running back; LB: Linebacker; WR: Wide Receiver; DB: Defensive back

Table 4: Overall random intercepts general linear mixed models

Model	Linear Acceleration	F Value	*P* Value
1	Ambient Temperature	11.26	0.01*
	WBGT	2.01	0.16
	Core Body Temperature	2.45	0.11
	In-Helmet Temperature	0.82	0.36
	Dehydration	3.48	0.06
Model	**Rotational Acceleration**	**F Value**	***P* Value**
2	Ambient Temperature	2.32	0.13
	WBGT	11.95	0.01*
	Core Body Temperature	0.15	0.69
	In-Helmet Temperature	0.33	0.56
	Dehydration	2.03	0.16
Model	**HITsp**	**F Value**	***P* Value**
3	Ambient Temperature	1.28	0.26
	WBGT	3.41	0.06
	Core Body Temperature	1.15	0.28
	In-Helmet Temperature	0.99	0.32
	Dehydration	2.29	0.13

* Asterisk denotes significant statistical findings.

Table 5: Individual random intercepts general linear mixed models

Model	Linear Acceleration	F Value	*P* Value
1	Ambient Temperature	1.90	0.17
	WBGT	1.12	0.29
	Core Body Temperature	0.81	0.37
	In-Helmet Temperature	0.43	0.51
	Dehydration	.49	0.48
Model	**Rotational Acceleration**	**F Value**	***P* Value**
2	Ambient Temperature	3.40	0.07
	WBGT	0.57	0.45
	Core Body Temperature	0.00	0.98
	In-Helmet Temperature	1.76	0.18
	Dehydration	0.23	0.63
Model	**HITsp**	**F Value**	***P* Value**
3	Ambient Temperature	2.35	0.13
	WBGT	0.02	0.89
	Core Body Temperature	0.55	0.46
	In-Helmet Temperature	3.74	0.05*
	Dehydration	1.65	0.19

* Asterisk denotes significant statistical findings.

Table 6: Comparison of the mean resultant linear acceleration, mean resultant rotational acceleration, and HITsp between sessions 1-3 to session 4. The associated 95% confidence intervals and *P* values are provided.

	N	Number of Impacts (% Total)	Linear Acc. (g) 95% CI				Rotational Acc. (rad/s^2) 95% CI				HITsp 95% CI			
			Mean	**L**	**U**	**P[1]**	**Mean**	**L**	**U**	**P[1]**	**Mean**	**L**	**U**	**P[1]**
Overall Model	18		$F_{3,44} = 0.68$, $P = 0.57$				$F_{3,44} = 1.80$, $P = 0.16$				$F_{3,44} = 1.18$, $P = 0.33$			
Session 1 *Ambient*-100.3° *WBGT*-45.8°	18	405 (35)	26.2	22.0	30.3	0.533	1624.9	1389.2	1860.6	0.051	15.1	13.3	17.0	0.130
Session 2 *Ambient*-86.2° *WBGT*-65.4°	17	217 (19)	23.7	22.0	23.3	0.638	1629.2	1479.1	1779.5	0.053	13.6	13.0	14.3	0.527
Session 3 *Ambient*-81.5° *WBGT*-74.2°	17	283 (25)	24.3	21.6	27.1	0.940	1598.3	1382.3	1814.3	0.064	14.2	12.9	15.4	0.261
Session 4[2] *Ambient*-72.4° *WBGT*-45.9°	15	235 (21)	24.4	20.7	28.2	(Ref)	1325.5	1095.3	1555.7	(Ref)	13.2	11.8	14.7	(Ref)
Total	18	1140	24.9	23.9	25.9	---	1568.8	1494.6	1643.1	---	14.3	13.8	14.8	---

Ambient and *WBGT* are the average of the readings across each test session.
Acc. Denotes acceleration
[1] P values are relative to the reference category used by the random intercepts general mixed linear model analyses.
[2] Denotes that reference category used in mixed linear models.

Table 7: Comparison of the mean resultant linear acceleration, mean resultant rotational acceleration, and HITsp between sessions 1, 3, and 4 to session 2. The associated 95% confidence intervals and P values are provided.

	N	Number of Impacts (% Total)	**Linear Acc. (g)** 95% CI				**Rotational Acc. (rad/s^2)** 95% CI				**HITsp** 95% CI			
			Mean	**L**	**U**	**P[1]**	**Mean**	**L**	**U**	**P[1]**	**Mean**	**L**	**U**	**P[1]**
Overall Model	18		$F_{3,44} = 0.68$, $P = 0.57$				$F_{3,44} = 1.80$, $P = 0.16$				$F_{3,44} = 1.18$, $P = 0.33$			
Session 1 *Ambient*-100.3° *WBGT*-45.8°	18	405 (35)	26.2	22.0	30.3	0.239	1624.9	1389.2	1860.6	0.974	15.1	13.3	17.0	0.124
Session 2[2] *Ambient*-86.2° *WBGT*-65.4°	17	217 (19)	23.7	22.0	23.3	(Ref)	1629.2	1479.1	1779.5	(Ref)	13.6	13.0	14.3	(Ref)
Session 3 *Ambient*-81.5° *WBGT*-74.2°	17	283 (25)	24.3	21.6	27.1	0.571	1598.3	1382.3	1814.3	0.751	14.2	12.9	15.4	0.451
Session 4 *Ambient*-72.4° *WBGT*-45.9°	15	235 (21)	24.4	20.8	28.0	.638	1325.5	1105.6	1545.4	.053	13.2	11.8	14.6	.527
Total	18	1140	24.9	23.9	25.9	---	1568.8	1494.6	16.43.1	---	14.3	13.8	14.8	---

Ambient and *WBGT* are the average of the readings across each test session.
Acc. Denotes acceleration
[1] P values are relative to the reference category used by the random intercepts general mixed linear model analyses.
[2] Denotes that reference category used in mixed linear models.

Table 8: Comparison of the mean resultant linear acceleration, mean resultant rotational acceleration, and HITsp between sessions 1-3 to session 4. The 15 subjects who participated in every session were only included in the analysis. The associated 95% confidence intervals and *P* values are provided.

	Number of Impacts (% Total)	**Linear Acc. (g) 95% CI**				**Rotational Acc. (rad/s^2) 95% CI**				**HITsp 95% CI**			
		Mean	**L**	**U**	**P[1]**	**Mean**	**L**	**U**	**P[1]**	**Mean**	**L**	**U**	**P[1]**
Overall Model		$F_{3,40} = 0.82$, $P = 0.48$				$F_{3,40} = 2.16$, $P = 0.11$				$F_{3,40} = 1.28$, $P = 0.29$			
Session 1 *Ambient*-100.3° *WBGT*-45.8°	314 (33)	27.19	22.2	32.2	0.48	1711.7	1434.3	1989.2	0.035	15.66	13.4	17.9	0.099
Session 2 *Ambient*-86.2° *WBGT*-65.4°	182 (19)	24.16	22.4	25.9	0.57	1673.3	1511.5	1835.1	0.060	13.70	12.9	14.5	0.597
Session 3 *Ambient*-81.5° *WBGT*-74.2°	236 (24)	25.18	22.3	28.1	0.911	1650.5	1405.9	1895.0	0.069	14.24	12.8	15.7	0.337
Session 4[2] *Ambient*-72.4° *WBGT*-45.9°	235 (24)	25.03	21.3	28.8	(Ref)	1363.4	1139.5	1587.3	(Ref)	13.38	11.9	14.8	(Ref)
Total	967	25.6	24.5	26.8	---	1606.9	1522.7	1691.2	---	14.4	13.8	15.0	---

Ambient and *WBGT* are the average of the readings across each test session.
Acc. Denotes acceleration
[1] P values are relative to the reference category used by the random intercepts general mixed linear model analyses.
[2] Denotes that reference category used in mixed linear models.

Table 9: Core body temperature relationships with the external temperature variables

Model	Variables	Mean change associated with 1°C increase in temperature measure	Standard Error	F Value	P Value
1	Core Body Temperature = Ambient Temperature	0.022	0.006	12.57	0.0004
2	Core Body Temperature = WBGT[a]	-0.015	0.005	7.79	0.005
3	Core Body Temperature = In-Helmet Temperature	0.016	0.007	5.38	0.02

[a] WBGT, Wet Bulb Globe Temperature

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