EFFECTS OF HIGH AND LOW IMPACT MAGNITUDES ON CONCUSSION MEASURES IN COLLEGIATE FOOTBALL PLAYERS

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ABSTRACT

MEGHAN ANN McCAFFREY: Effects of High and Low Impact Magnitudes on Concussion Measures in Collegiate Football Players
(Under the direction of Kevin M. Guskiewicz)

The purpose of this study was to investigate the effects of a theoretical concussive injury threshold on balance and neurocognitive performance in the absence of self-reported symptoms immediately following two different impact conditions (high and low) sustained in 43 Division I football players. A double-blind study utilized the Head Impact Telemetry System to classify subjects into the two testing conditions. Data were collected during the 2005 football season and 2006 spring season. Balance performance, neuropsychological functioning and self-reported symptoms were all assessed and separate repeated measures ANCOVA's were performed for each. Our data analyses resulted in significant differences for only a few of the comparisons made between the low and high magnitude conditions compared to baseline. Overall, our findings suggest that sustaining an impact greater than 100g does not result in acute observable balance and neurocognitive deficits.

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PREFACE

My first experience with concussions was my first semester in my undergraduate career. My clinical site was at a private boarding high school. During the first semester I had the opportunity to travel with my school's football team for a big match up. I was excited for my first big away trip with a team. The game was full of big hits, questionable calls by the referees, and lots of shouting and the typical football atmosphere. It was in the second half of the game when one of my athletes sustained a hard hit to the head and his teammates and coach told me he had no idea what plays they were running. It was that time that the coach pulled him from the game and had me evaluate him. Having no direct experience with concussions and evaluating them, I was nervous about what to do. Upon my initial evaluation, it however, was obvious that he had a concussion and would not be returning to the game. The part in my evaluation when the boy's parents came over to check that he was ok was the point that drove home the purpose of my thesis. His parents spoke to him and I stood there and watched in shock as the boy had no recognition of his parents whatsoever. That moment sparked my interest in concussions and the etiology of the injury, the diagnosis, and return to play aspects dealing with MTBI. It is that particular image that has stayed with me and will continue to throughout my career.

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LIST OF ABBREVIATIONS

MTBI: mild traumatic brain injury

SAC: Standardized Assessment for Concussion

BESS: Balance Error Scoring System

NATA: National Athletic Training Association

HITS: Head Impact Telemetry System

SRT 1: Simple Reaction Time 1

SRT 2: Simple Reaction Time 2

MTH: Math Processing

MSP: Match to Sample

PRT: Procedural Reaction Time

CS9: Code Sub 9

MS6: Memory Search 6

ANAM: Automated Neuropsychological Assessment Metrics

GSC: Graded Symptom Checklist

ImPACT: Immediate postconcussive assessment & cognitive test

SOT: Sensory Organization Test

RTP: Return to Play

IRB: Institutional Review Board

ANCOVA: Analysis of Covariance

MRI: magnetic resonance imaging

CSF: cerebral spinal fluid

SIS: Second Impact Syndrome

CRI: concussion resolution index

NFL: National Football League

NCAA: National Collegiate Athletic Association

NOCSAE: National Operating Committee for Safety in Athletic Equipment

ADD: Attention Deficit Disorder

CHAPTER I

INTRODUCTION

Mild traumatic brain injuries are of growing concern throughout competitive sports. A mild traumatic brain injury (MTBI) is defined as a traumatically induced alteration in neural function that may or may not involve loss of consciousness. (Collins, Grindel et al. 1999) In the context of sports injuries, MTBI is often referred to interchangeably as a concussion. Due to the detrimental effects associated with MTBI, this type of injurious event is of great concern for sports medicine professionals. Despite the amount of research being conducted in the field of sports-related MTBI, there is much still unknown about the injury. An estimated 300,000 sports-related MTBI's are reported each year in the United States among children, adolescents, and young adults. (1997) Published research has promoted improvements in equipment, and changes in rules have been introduced in an attempt to reduce the incidence of MTBI among a continually growing athletic population. (Mueller 2001) Despite the improvements to facial and head protection, and the implementation of new rule changes, the number of athletes that sustain MTBI's remains high throughout athletics. (McCrea, Guskiewicz et al. 2003)

There is arguably no one superior mechanism for managing MTBI. Over 20 grading scales and return to play guidelines have been presented in the literature, although none have been empirically supported. The continual evolution of our knowledge of MTBI has not allowed for a definitive grading scale or return-to-play guideline system within the sports medicine community. American football, often categorized as a high risk contact sport, is one of the most commonly studied sports in the sports-related MTBI research model since athletes have a relatively high incidence of MTBI's. Players repeatedly sustain impacts to the head that are comparable to those sustained in car crashes. (Zhang, Yang et al. 2004) Zhang et al.'s observations have been corroborated in the last few years, as more information regarding the nature and magnitude of head impacts in football has been published.

Many MTBI's are underreported and younger athletes are less likely to report his or her symptoms to the certified athletic trainer entrusted with his or her immediate care. (Collins and Hawn 2002) Often times, the athlete lacks the education about the symptoms of MTBI and, therefore, will not realize he or she has a MTBI. In addition, some athletes play in a very competitive atmosphere and feel a great deal of pressure to excel at the sport he or she is playing. (Collins and Hawn 2002) Hence, even if the athlete is aware of the injury he or she has sustained, the symptoms are often ignored and participation is continued. The latter can predispose an athlete to a greater risk for serious complications as a result of a MTBI, such as second impact syndrome. In this respect, advancing technology may help certified athletic trainers to recognize a MTBI by monitoring the impacts sustained by the athletes under our care.

Studies have shown that sideline tests are able to detect impaired neurocognitive and neuromotor functioning. There is a growing trend to record pre-season baseline measures on neurocognitive and neuromotor tests; this has provided valuable information to properly recognize and manage this condition. Sideline tests such as the Standardized Assessment of Concussion (SAC) and Balance Error Scoring System (BESS) allow for the convenience of immediate sideline testing during practices or games. Continuing research in the area of postural control and neuropsychological testing of concussed athletes will allow improve the objective evaluation of MTBI. However, there is still much to be learned regarding exactly how the impacts that a football athlete sustains on a daily basis affects the brain. The biomechanics of a MTBI remain unclear for medical professionals; current research, however is attempting to answer some of these questions.

Statement of the Problem

Mild traumatic brain injuries cause microscopic changes that occur at the cellular level in the brain and are often a result of deceleration force. (Gebke 2002) An athlete that has sustained a concussion may present with symptoms such as headache, blurred vision, confusion, inability to remember where he or she is, or what he or she was doing. (Ferguson, Mittenberg et al. 1999) Although a number of symptoms typically follow a MTBI, these symptoms might not present immediately; they often only appear 24 hours after the initial impact suffered. By further examining the location, duration, and magnitude of impacts that football players are sustaining on a daily basis, the medical personnel will be able to provide the best medical care to the athlete in terms of the immediate recognition of injury and the effects it has on the body. The primary purpose of this study was to compare measures of balance performance and neurocognitive function at baseline to those obtained after the participant had sustained an impact to the head with a magnitude of linear acceleration of at least 100 g. The secondary purpose of this study was to compare the measures of balance and neurocognitive function at baseline to those obtained after the participant had sustained an impact to the head with a magnitude of linear acceleration of no greater than 70 g. The overall objective was to observe if there were acute effects of magnitude of head impacts in the participants' balance and neurocognitive performance in the absence of self-reported symptoms.

Research Questions

1. Does an impact to the head with a linear acceleration of at least 100 g result in acute deficits in balance and neurocognitive performance in football players when compared to their baseline measures despite the absence of self-reported symptoms?
2. Does an impact to the head with a linear acceleration of no greater than 70 g result in acute deficits in balance and neurocognitive performance in football players when compared to their baseline measures despite the absence of self-reported symptoms?

Null Hypotheses

1. An impact to the head with magnitude of linear acceleration of at least 100 g will not result in deficits in balance and neurocognitive performance relative to the athletes' preseason baseline measures.
2. An impact to the head with a linear acceleration no greater than 70 g will not result in deficits in balance and neurocognitive performance in football players when compared to their baseline measures despite the absence of self-reported symptoms.

Research Hypotheses

1. An impact to the head with a linear acceleration of at least 100 g will result in deficits in balance and neurocognitive performance relative to the athletes' preseason baseline measures.

2. An impact to the head with a linear acceleration of no greater than 70 g will not result in deficits in balance and neurocognitive performance relative to the athletes' preseason baseline measures.

Definition of Terms

1. **Experimental session:** Practice or game situation in which participants receive an impact to the head that measures at least 100 g.
2. **Control session:** Practice or game situation in which participants receive an impact to the head no greater than 70 g.
3. **Mild traumatic brain injury (MTBI)**: immediate and transient post traumatic impairment of neural functions, such as alteration of consciousness, disturbance of vision, equilibrium, etc. due to biomechanical forces.(Congress of Neurological Surgeons, Committee on Head Injury Nomenclature 1966)
4. **Concussion**: an injury resulting from impact with an object. Partial or complete loss of function, as that resulting from a fall or blow. {Venes, 1997 #108}
5. **Standardized Assessment of Concussion (SAC)**: a systematic sideline evaluation tool for the immediate assessment of concussion in athletes. The form tests immediate, delayed recall, digit span, coordination, upper and lower limb strength, sensation and function, as well as vision.
6. **NeuroCom**: a system designed to assess vestibular and somatosenosry processing during balance tasks.
7. **Automated Neuropsychological Assessment Metrics (ANAM)**: Computerized neuropsychological testing battery which assesses simple reaction time, mental processing, attention, working memory, and concentration.

8. **Graded Symptom Checklist (GSC)**: An eighteen point Likert scale checklist. The list of eighteen self-reported symptoms commonly associated with MTBI are rated by the athlete based on severity (0=none, 1=mild, to 6=severe).

Operational Definitions

1. **Balance performance**: the ability of an athlete to maintain an upright position in normal stance position for him or her and maintain the center of gravity within the body's base of support using a complex network of neural connections and centers that are related by peripheral and central feedback mechanisms.

2. **Impact threshold**: proposed minimum limit at which head contact sustained by a football player will predispose the athlete to a mild traumatic brain injury. For this study, the threshold will be set at 100 g.

3. **Gravity (g):** linear acceleration as measured by units of the force of gravity. For example, 100 g is a linear acceleration equivalent to 100 times the force of gravity.

4. **Frequency:** the number of times that a player has received a head contact exceeding the impact threshold.

5. **Neuropsychological testing:** a series of written- or computer-based exercises in which the athletes' cognitive functioning is assessed. Paper and pencil tests include but are not limited to, the Hopkins Verbal Learning Test (HVLT), STROOP, and Color Word Association Test (COWAT).

6. **Postural sway**: any deviation in the anterior-posterior or medial-lateral plane of an individual's center of pressure from the neutral center of pressure as measured on a force plate.

Limitations

1. Subjects experienced varying levels of exposure to potential injury.
2. Concussion history was self-reported by the subjects participating in the study.
3. Subjects were unable to complete the study due to an injury sustained during the season.
4. The athletes were not all tested at the exact same following the experimental or control session.
5. Subjects provided an honest effort in performance of postural stability testing.
6. Subjects provided an honest effort in performing neuropsychological testing

Delimitations

1. 100 g was set as the criterion threshold limit.
2. Testing the subjects was done within 24 hours of the experimental or control session.
3. If a player became symptomatic, he was removed from the study due to exclusion criteria.

Assumptions

1. The Head Impact Telemetry (HIT) System provided accurate information about location and magnitude of impacts to the head during participation.
2. Athletes practiced and played with proper technique as stated by the rules of the National Collegiate Athletic Association.
3. The athletes reported previous concussion history and other previous medical conditions on their health history questionnaire honestly.

4. The NeuroCom & ANAM programs functioned properly, and were reliable in their measures.
5. The athlete did not have any factors that might potentially be attributed to MTBI other than playing football (i.e. excessive dehydration, supplement use other than that given by the strength and conditioning staff).

Significance of the Study

Investigating the balance and neurocognitive performance of football players after sustaining an impact greater than a speculated injury threshold has not yet been conducted. A series of studies conducted by Pellman et al. (Pellman 2003; Pellman, Viano et al. 2003) have proposed a theoretical threshold for concussive injuries. Much is still unknown about the clinical manifestations observed in athletes following measurable impacts greater than this theoretical threshold. As a result of ongoing research, the Head Impact Telemetry (HIT) System has been designed to look at the head impacts that football players regularly sustain. The HIT System is comprised of six-single axis accelerometers placed in a player's helmet to measure the impact magnitude in units of gravity, duration of head impact in milliseconds, and the location of the impact sustained. Given the nature of this technology, it is possible for a large amount of information to be collected. A study that correlates the magnitude of an impact to the potential changes in neurocognitive and neuromotor functioning has never been conducted in the context of a field study. Initial steps have been taken in this direction by Pellman et al. They have conducted studies in which injury video footage has been analyzed and a recreation of these head impacts have been conducted in laboratory isolation. (Pellman

EJ 2003) With this information and data that has been published, advancing on this area of research is imperative.

Recent studies have reported the dangers of multiple MTBI's throughout an athletic career and in addition to the life-threatening repercussions of second impact syndrome (SIS). (Mueller 2001) Generally occurring in adolescents and young adults, SIS is a condition that may occur when an athlete sustains a second MTBI before complications from the first injury have yet to resolve; the second, often a seemingly minor blow, can cause fatality. (Cantu 2003) A main concern in the context of SIS is the amount of concussions that go unreported. The underreporting of head injuries is often a direct result of the athlete's unwillingness to inform the medical professional since doing so often results in a withholding from play. It may also be the result of a lack of education about the inherent risks associated with a premature return to play (i.e. SIS). This study evaluated proposed threshold limits in clinical measures of balance and neuropsychological testing. With the technology and the information from this study, the medical professional has more information available to him or her to better direct medical care for an athlete that would otherwise have repeated their injury. The results of this study may allow the clinician to more effectively treat and protect the athlete from the detrimental effects of MTBI. It will also allow researchers and clinicians to better understand the forces that the head receives during football participation and how that relates to changes in balance performance and neurocognitive function.

CHAPTER II

REVIEW OF THE LITERATURE

As the sport of football continues to become increasingly competitive at all levels, rate of injuries also continue to rise. It is unique to find an athlete who has gone through his or her athletic career without sustaining any kind of trauma to his or her body. Mild traumatic brain injury (MTBI), also know as concussions in the realm of athletics, are a different nature of injury. Mild traumatic brain injury was defined in 1966 by the Congress of Neurological Surgeons as "an immediate and transient impairment of neural function such as an alteration of consciousness, disturbance of vision, equilibrium, and other similar symptoms." (Committee on Head Injury Nomenclature, Bailes & Cantu 2001) Research has provided information to show that equipment can help prevent MTBI's, while signs and symptoms help diagnose and neuropsychological testing manages MTBI's or the return to play criteria. Mild traumatic brain injuries have been a perplexing condition to the medical profession. The staggering number of MTBI's that are brought to the emergency room prove how vital it is for the medical professional, especially for certified athletic trainers and team physicians to be sensitive to signs and symptoms of concussions, and have sound, objective assessment methods to evaluate and manage these injuries. A vast array of research studies have been published which have helped reveal important information about concussions but the medical field has yet to reach a consensus about a standard grading scale or return to play criteria. Even with rule changes and equipment alterations, MTBI's are still common among competitive athletes. More prevalent in contact sports such as boxing, football, rugby, ice hockey, soccer and lacrosse, MTBI's are a serious medical issue and should never be overlooked. With a number of accomplished professional athletes forced into early retirement, public awareness of this type of injury has lead to a greater demand to better understand the nature of MTBI. Advances in research in the field of bioengineering may be able to allow medical professionals to improve their understanding of the forces that are imparted on the head in American football leading to more conclusive findings related to the pathophysiology of concussions in athletics.

Epidemiology of Concussion

Incidence

Mild traumatic brain injuries are not limited to one particular sport or one type of athlete. Trauma to the cranium is among the deadliest injury in sports and MTBI is grouped under this category of head trauma. (Mueller 2001) Nine hundred deaths due to an injury to the brain are seen each year in sports. (Sosin, Sniezek et al 1996) There are over 300,000 sports related brain injuries each year and 25,000 are seen in high school football alone. (Grindel 2003; Longhi, Saatman et al. 2005) A study conducted looking at the incidence among high school sports found an alarming number of MTBI's. In this study, ten sports were tracked over the course of three years in regards to the number of MTBI's and causation of the MTBI's. The National Athletic Trainers' Association (NATA) found concussions in football, basketball, soccer, wrestling, field hockey, baseball, softball, volleyball. (Powell 2001) Incidence of MTBI's was much greater in game situations in all the sports with the exception of wrestling and volleyball. The mechanism of injury was almost always some type of collision with another player or an object. (Powell and Barber-Foss 1999) Organized and recreational sports have an incurred risk of MTBI's. Equestrian, cheer leading, skateboarding, roller-skating, in-line skating, cycling, skiing and snowboarding are activities were MTBI's have been reported. (Bailes and Cantu 2001; Bailes and Hudson 2001) Although football is the most common organized sport which concussions are seen, there are other sports in which the incidence is just as high. Boxing, ice hockey and rugby are among the more common organized sports that reports MTBI's. (Bailes and Cantu 2001) Each sport varies in the theories as to why the incidence is so prevalent. The sheer objective of the boxing (to damage the opponents cognitive functioning in simple terms for the boxer, to knock the opponent out) and lack of equipment contribute to the frequent rate of concussions. High contact rate in rugby combined with little equipment also aids in the high injury rate of MTBI. Ice hockey although having comparable incidence rate to football, have seen decreases in the past few years due to changes in protective equipment, specifically in helmets. (Bailes and Cantu 2001)

Anatomy of the Brain

Cranial Meninges

The cranial meninges isolate the brain and create the circulatory system of the brain. There are three main meninges. The dura mater is the outermost layer. It is thick, more durable and denser compared to the other two layers. Dural infoldings are found in this layer which separates the various lobes of the brain. The middle meningeal artery is the largest meningeal artery of the dura mater; its importance is understood as it is almost always involved in cases of reported fatalities associated with MTBI. The arachnoid mater lies against the dura mater and is said to be web-like and delicate in nature. The pia mater is the innermost layer and is extremely vascular. These layers enclose the cerebrospinal fluid which provides the brain its buoyancy within the cranium. (Martini 1998)

Cerebrospinal Fluid

Cerebrospinal fluid (CSF) plays an integral role in protecting the brain and also in the biomechanics of MTBI. Specialized cells called ependymal cells secrete CSF into the ventricles of the brain. This fluid allows the brain to float in the cranium while supporting it. In addition, the CSF protects the neural structures surrounding the brain and regulates the transportation of nutrients, wastes and chemical neurotransmitters. However, it is this fluid that facilitates the acceleration-deceleration type of MTBI mechanism. When the head has a rapid change in linear or rotational movement, the brain lags behind the skull while floating in the CSF. (Martini 1998) Thus, as the skull begins moving in another direction, the brain will hit the skull due to the delay in momentum. This impact of the brain on the skull creates trauma to the brain and can also cause microscopic structures to tear and bleed.

Frontal Lobe

This area of the brain is located anteriorly to the central sulcus. Its functions are planning, organization, problem solving, selective attention, behavior and emotions. The frontal lobe has been shown to be linked to memory and language processing. (Choi, Lee et al. 2005; Thompson-Schill, Bedny et al. 2005) This lobe is very susceptible to effects of head injury and sustains many lesions as a result.

Temporal Lobe

Posterior to the lateral sulcus lays the temporal lobe. There are two temporal lobes located in the brain. The right temporal lobe is typically associated more with visual memory; this is in contrast to the left temporal lobe, which is associated with verbal memory. Both temporal lobes function together to identify smell and short term memory. Studies have shown the medial temporal region contains the majority of family, personal memories and recognition in humans. (Bachevalier and Vargha-Khadem 2005; Manning, Chassagnon et al. 2005)

Occipital Lobe

Separated from the parietal lobe by the parieto-occipital sulcus, the occipital lobe is the most posterior lobe found in the brain. Vision is controlled by this lobe; more specifically, it regulates the recognition of shapes and colors. Studies in individuals with lesions, trauma to the occipital lobe almost always have issues with vision. Hallucinations, distorted vision, and lack of vision have been observed in those with injury and disease affecting the occipital lobe. (Choi, Lee et al. 2005)

Parietal Lobe

The right and left parietal lobes function to distinguish touch and pressure. The right parietal lobe particularly focuses on visuospatial recognition, determining where things are in space and relation to the body. The left lobe concentrates on comprehending language both auditory and visually.

The Cerebellum

The cerebellum is located posterior to the brain stem and pons as well as inferior to the cerebrum. Balance and muscle coordination are controlled by the cerebellum. (Martini 1998), (Morton and Bastian 2004) Schmahmann states that disorders affecting the cerebellum are consistent with deficits of muscular contraction resulting in ataxia, dysmetria, dysarthria, and dysphagia. (Schmahmann 2004) There has also been research into control over higher order functions such as emotions and personality. (Schmahmann 2004) Research has found genetic abnormalities on the spinocerebellar ataxsis have been linked to problems with memory, concentration, an inability to efficiently reason, impulsitivity, and emotional instability. (Gambardella, Annesi et al. 1998; Storey, Forrest et al. 1999)

The Brainstem

The brainstem regulates life such that essential physiological actions are controlled by this structure. Breathing, digestion, heart rate, blood pressure, awake and alert cycles, are all regulated by the brainstem. Damage to the brainstem, even sometimes minor, can have lethal consequences. Intracranial hemorrhaging more often than not results in brainstem herniation; the latter typically results in death. (Martini 1998)

Integrative Centers

Integrative centers are spread among the various lobes of the brain and have a variety of purposes. There are three main integrative centers: the prefrontal cortex, the speech center, and the general interpretative area. The prefrontal cortex communicates the intellectual functions with the rest of the areas of the brain. It analyzes situations and predicts what will happen in future events. The origins of frustration, tension, and anxiety are developed here. The speech center regulates breathing, vocalization and formation of words. There is a motor speech area named Broca's area and a receptive speech area. The latter interprets the motor commands given by the motor speech area. Damage to the speech center will result in speech difficulties ranging from trouble forming auditory words to using the appropriate words to relay coherent information. The general interpretive area is the collection center. It takes information from all the other areas of the brain and interprets the commands from these different areas. It consists of what someone's personality is and how he or she understands what is spoken or written. (Martini 1998)

Mechanism of Injury

There are several means by which an athlete can sustain a MTBI. An impact or compressive force, a shearing force, a rotational force and an acceleration or tensile force are all mechanisms of MTBI. (Echemendia and Julian 2001; Asplund, McKeag et al. 2004) Acceleration-deceleration is the most common mechanism for MTBI seen in sports, particularly football. (McCrory, Johnston et al. 2001) The brain is contained in the cranium by the bones of the skull and rests in CSF. When the head is moving the brain moves with it. With a sudden, abrupt change in direction, the brain tends to lag behind the skull itself, thus hitting the side of the skull with a significant force. The result of this force is said to cause shearing and tearing of the axons in the brain. (Barth, Freeman et al. 2001; Broglio, Guskiewicz et al. 2004) Impact loading results in the initiation of the cerebral cascade. A cerebral cascade is defined in the literature as the pathophysiological response in the brain as a result of trauma to the brain. (Bailes and Cantu 2001) Rotational movements can also lead to MTBI. The movement of the brain causes microscopic tearing and bleeding within the various layers of the cerebral mater. A rapid alteration in the head's velocity over time will cause trauma to the brain tissue. (Barth, Freeman et al. 2001) The more traditional mechanisms of MTBI would be the impact and loading type. A direct impact to the cranium will cause disruption of a delicate balance of neurotransmitters in the brain. A number of theories have been established in terms of the biomechanics of MTBI. Newton's second law ($F = m \cdot a$) has prevailed as an explanation of mechanics of the acceleration-deceleration type and MTBI of this nature will suffer the greatest axonal injury and impairments in neuropsychological behavior. (Barth, Freeman et al. 2001) The magnitude and force delivered by the object is determined by the characteristics of the object. The more rapid the load is applied, the less force it has to be applied with to cause damage to the brain. Lateral motions of the brain cause the most damage when compared to sagittal movements.(Echemendia and Julian 2001)

Pathophysiology of MTBI

Despite a lack of obvious deformity from direct impact, forces can still be present to cause lethal damage. (Barth, Freeman et al. 2001) The trauma induced to the brain causes a chain reaction on the cellular level. Maximum dysfunction in the brain is seen within the first three days following the insult and scores on neuropsychological tests are the lowest. (Buczek, Alvarez et al. 2002) The impact or acceleration-deceleration forces that cause the temporary displacement of the brain begins the sequelae of events known in literature as the cerebral cascade. (Echemendia and Julian 2001; Giza and Hovda 2001) A disruption of numerous neurons and capillary damage has been seen in various studies. (Bailes and Hudson 2001) Axonal stretching as a result of the acceleration-deceleration forces triggers a release of neurotransmitters. (Grindel 2003) An immediate release of neurotransmitters, particularly acetylcholine, causes the depolarization of neurons. This depolarization causes an imbalance in the sodium-potassium pump. There is an efflux of potassium, caused by glutamate, and an influx of calcium. (Bailes and Cantu 2001) This disruption of the sodium-potassium pump causes the cells to work twice as hard. An increase in ATP causes an increase in glucose which creates a hypermetabolic state and diminished cerebral blood flow. Increased glucose levels can remain elevated for four hours in certain areas of the brain. (Giza and Hovda 2001) The elevated glucose levels were seen in the injured cortex of male rats after sustaining a standardized parasagital fluid percussion brain injury. (Buczek, Alvarez et al. 2002) The increased glycolysis, which lasts at least thirty minutes, produces an excess of lactate. Thus, increases in calcium levels in the cells, seen in rats for two to four days, interferes with mitochondrial oxidative metabolism and accentuates the negative detoriating effects occurring to the neurons. High levels of calcium are the primary cause in neuronal death. (Stelmasiak, Dudkowska-Konopa et al. 2000) A reduction in cerebral blood flow is seen as a result of increased calcium flux. (Gebke 2002) Susceptibility to mitochondrial damage is greater during MTBI and this damage causes a delay to the ATP synthesis, vital to normal neuronal functioning. (Buczek, Alvarez et al. 2002) Acidosis causes membrane damage and alters the permeability of the blood brain barrier. Magnesium is another mineral that is affected during this neurometabolic cascade following trauma. There is a reduction of the levels cause neuronal dysfunction whereas normally it maintains the cell membrane permeability and initiates protein synthesis. An alteration in NMDA (N-methyl-D-aspartame) occurs and can last up to one week post injury and if over stimulation of the neurons occurs there is a greater risk for seizures and more cell death to happen. (Giza and Hovda 2001) A study performed on rats that were inflicted with concussive insults reported that it took ten days for resolution of neuronal functioning and chemical balance in the brain to occur. (Cantu 2001)

Types of Hematomas

Subdural Hematoma

Death is probable with those athletes that sustain a subdural hematoma, as it has been listed in literature as the most common cause of head injury death. (Logan, Bell et al. 2001) There are two main classifications: acute and chronic. Acute hematomas are the most dangerous and lethal. This is defined as bleeding within the subdural space. Symptoms usually do not present until 48 to 72 hours after insult and complications can occur. Complications usually result in irreversible damage and death despite surgical intervention. Chronic subdural hematomas are found around a week later when symptoms start manifesting post concussive symptoms. (Bailes and Hudson 2001)

Epidural Hematoma

This medical condition occurs when a traumatic force has caused blood to accumulate between the dura mater of the brain and the skull. The mechanism of this injury is result of an acceleration-deceleration force. Commonly associated with this type of hematoma is a skull fracture. The skull fracture often causes a laceration in the middle meningeal artery or vein and the athlete will present with some type of deformity. Athletes with an epidural hematoma have a period of time in which normal functioning occurs until the blood has significantly pooled. This pooling of the blood causes compression and herniation of the brain stem. (Bailes and Hudson 2001) Epidural hematomas are seen in sports that do not require helmets or other protection for the head. (Bailes and Cantu 2001)

Intracerebral Hematoma

A localized collection of blood within the brain is identified as an intracerebral hematoma. Typically there is a distinct deficit noted during an evaluation of an athlete assumed to have this but coma and death may be the end result if it is not diagnosed within a relatively short period of time. (Bailes and Hudson 2001)

Second Impact Syndrome

Second impact syndrome (SIS) involves two consecutive impacts to the head occurring when a second impact, often minor, is imparted when symptoms of the first have yet to resolve. (Echemendia and Julian 2001; Grindel, Lovell et al. 2001; Collins and Hawn 2002) The second impact does not have to be one of great magnitude for the cerebral bleeding to accumulate and markedly increase intracranial pressure. The drastic increase in intracranial pressure leads to brain stem herniation thus causing death. (McCrory and Berkovic 1998; Randolph 2001) This occurs within two to five minutes from the time of second impact. An animal design looked at the effects of two concussions 24 hours apart and found no histological damage but long term microscopic evidence of axonal injury and alterations in motor tasks were found. This study demonstrated that once a concussion is sustained there is a period in which the person is vulnerable to another concussion and there are prolonged cognitive and neuromotor impairments as a result of repeated impacts. (Longhi, Saatman et al. 2005) Controversy over this condition is due to the lack of valid documentation and basis of hearsay. (McCrory and Berkovic 1998) McCrory analyzed seventeen case reports of SIS and found no definite cases. The five probable cases were in young male athletes in contact sports. However, there have been unexplained fatalities from impacts to the head that have been speculated to be from SIS. As a result it is imperative that clinicians do not return an athlete back to activity if he or she is still symptomatic.

Post-concussive syndrome

Post concussive syndrome is a lingering result of a MTBI in which the patient experiences prolonged symptoms. Headache, dizziness, nausea, tinnitus, depression, irritability, slowed mental processing, impaired attention, and memory deficits are all associated with postconcussive syndrome. It is typically it is defined as patients reporting two or more symptoms at 3 months post injury. (Ferguson, Mittenberg et al. 1999) A person with this syndrome can experience these symptoms for years after suffering the initial MTBI, and in some cases can be permanent. (Grindel, Lovell et al. 2001) Posttraumatic headache is the most common complaint of patients suffering from this syndrome. (Collins, Grindel et al. 1999) A study on concussed athletes found those that had headaches seven days post injury performed significantly lower in reaction time and memory than those who were not experiencing a headache. In addition, these athletes experienced more post concussive symptoms than those that had no headache. Thus, these athletes experiencing headache 7 days post injury showed a slower neurocognitive recovery curve.

Grading Scales

There are over 20 documented grading scales for MTBI's, none of which has become the standard when assessing a MTBI's. The two most commonly used scales are the American Academy of Neurology and the Cantu Grading System. (Grindel 2003) The three main classification categories are Grade I, (mild), Grade II, (moderate); Grade III, (severe).

The inconsistencies of the grading scales make it difficult for clinicians to properly assess the nature of the MTBI's and as a result, unable to follow a set protocol. Current evaluation of MTBI's has moved away from quantifying and labeling the injury and more towards objectively treating the symptoms being experienced.

The Glasgow Coma Scale is a recent addition in the evaluation of MTBI's. Using the symptoms the athlete presents with, he or she is scored accordingly and determined which category to be placed in. (Gebke 2002) The most commonly used scales consist of three grades. Mild traumatic brain injuries can present with a wide array of symptoms, not all of which are present in each case, making it more difficult to set a standard structure to classify them. All grading scales are based primarily of self-report of symptoms, which most researchers have acknowledged is an acceptable limitation.

Various Testing for Mild Traumatic Brain Injury

Diagnostic Imaging Testing

Diagnostic imaging for MTBI is not as conclusive as once thought. Computerized tomography (CT) scans, magnetic resonance imaging (MRI), and electroencephalographs (EEG) although capable of identifying structural damage are insensitive to functional injuries such as MTBI.(Echemendia, Putukian et al. 2001; Collins and Hawn 2002) Not surprising, athletes have demonstrated normal imaging results despite cognitive compromise displayed by decreased scores on neuropsychological tests. (Putukian 1996) Thus, unless there is a severe intracranial disturbance, then any of these diagnostic tools will not be helpful in determining if the athlete does in fact have a MTBI.

Neuropsychological Testing

Many times there are postconcussive symptoms that go unnoticed or underreported by the athlete. Microscopic trauma in the brain might only present with subtle changes in one or numerous areas of the brain function. These changes might not be observed by the athlete or the medical professional on the initial evaluation. Thus, it would be clinically significant to test the athlete and see where the deficits are that the athlete is suffering from. Neuropsychological testing is the most sensitive method of detecting postconcussive symptoms. (Lovell and Collins 1998; Randolph 2001; Gebke 2002)

Neuropsychological testing began in the mid-1970 with a study conducted by Barth. He administered baseline testing for 2,300 athletes and retested those athletes that had suffered a concussion. Macciocchi et al. was the first large scale study to use the paper-and pencil tests. (Macciocchi, Barth et al. 1996) Since then, the popularity of using neuropsychological testing as an evaluation and diagnostic tool has increased steadily as more research is being conducted to prove its importance. Athletes have come to accept neuropsychological testing as part of the medical care that the sports medical staff provides. (Pellman, Lovell et al. 2004) A majority of professional football teams, collegiate contact sports and high school contact sports all have begun implementing a battery of neuropsychological tests. (Grindel, Lovell et al. 2001) The Pittsburgh Steelers were the first professional football team to place the neuropsychological testing in place and were soon followed by the National Hockey League. (Macciocchi, Barth et al. 1996; Lovell and Collins 2002)

Neuropsychological tests are designed to target faculties of brain function commonly affected by MTBI. These include concentration, attention, memory, information processing speed, motor speed and coordination. (Lovell and Collins 1998; Echemendia and Julian 2001) The true clinical significance of the neuropsychological testing is seen when the athlete has completed a preseason baseline test. (Grindel, Lovell et al. 2001) This allows the medical professional to compare the post-injured values individualized with those pre-injury scores. Any initial deficits will be detected and explored as learning disabilities but once a MTBI has been sustained the scores are compared to baseline and any decreases may be attributed to the trauma suffered. (Lovell and Collins 1998) Along with the grading scales and return to play criteria there is no standard battery of tests or neuropsychological assessment for athletes. Numerous neuropsychological tests are available to use in a battery, such as:

Paper and pencil tests

1. Trail Making Tests, Parts A & B
2. Stroop Test
3. Digit Span from the Wechsler Memory Scale-Revised
4. Symbol Digit Modalities Test
5. Controlled Oral Word Association Test
6. Hopkins verbal Learning Test
7. Letter and Numbering Sequencing from Wechsler Memory Scale- III

Computerized tests

8. MicroCog
9. CogScreen
10. Automated Neuropsychological Assessment Metrics (ANAM)
11. Vigil
12. Immediate postconcussion assessment and cognitive test (ImPACT)
13. Concussion Resolution Index (CRI)

(Lovell 1998)

Studies conducted by Collins have revealed that football players at the collegiate level with a history of repeated MTBI perform lower on the neuropsychological tests post injury when compared to baseline measures than those who have not suffered a MTBI. Collins subjected 393 Division I football players to a battery that consisted of eight paper and pencil neuropsychological tests. This study revealed that those players having suffered multiple concussions scored lower on the baseline testing than those without a previous history of head trauma. In addition, those athletes who sustained a MTBI scored lower on those tests taken after the injury when compared to the baseline scores each received individually. Significant validity and reliability was shown for the tests administered. (Collins, Grindel et al. 1999; Collins and Hawn 2002) In addition, it has been shown that neuropsychological tests are reliable and valid in assessing those deficits that show change with MTBI's. (Rimel, Giordani et al. 1981; Dikmen, McLean et al. 1986)

Not only is neuropsychological testing useful in whether or not an athlete has suffered a MTBI but also in assisting in the return-to-play decision. Improvements can be tracked over any given period of time that the medical professional deems necessary. (Oliaro 1998) However, testing is typically performed within the first twenty-four hour period, with follow-up assessments taking place on days one, three, five, seven, and fourteen. Medical professionals will base their return to play decision based upon the scores of the neuropsychological test result in conjunction with a thorough physical or clinical examination. A recently published study found that concussed athletes performed significantly worse than those that did not sustain a concussion and most of the deficits were seen in the first 48 hours of injury. (Bleiberg, Cernich et al. 2004) It has been generally accepted that athletes with abnormal neuropsychological test scores, indicating abnormal brain function, when compared to baseline be withheld from activity until the scores return to the baseline values. (Lovell and Collins 2002) The neuropsychological data was the only revealing information to the deficits still being experienced by the athlete. The post concussive symptom scale did not reveal any difference among the two groups at 48 hours post injury. This reaffirms the significance of the neuropsychological testing battery in regards to return to play decisions (RTP) due to its ability to identify subtle differences in the different cognitive domains. (Echemendia, Putukian et al. 2001)

Standardized Assessment of Concussion

The Standardized Assessment of Concussion (SAC) is a brief mental status exam which takes approximately 6 minutes to administer and can be done on the sideline to assess the immediate severity of a MTBI. (McCrea 2001; Randolph 2001; Collins and Hawn 2002) The SAC was developed modeling suggestions from the AAN Practice Parameter and the Colorado Guidelines. (Kelly, Nichols et al. 1991; 1997) It focuses on four main domains, (orientation, immediate memory, concentration and delayed recall) affected by MTBI and scores out of a possible thirty possible points. Two alternate forms are available to reduce the practice effects often seen with traditional neuropsychological tests. Deficits in neurocognitive functioning have been detected by administration of the SAC, despite variables unable to be controlled such as environment. (McCrea 2001) The SAC has also been proven to be effective in detecting improvements over time as the patient recovers from the MTBI. (McCrea, Kelly et al. 1998) A study conducted among 141 high school football players found those that were concussed obtained significantly lower scores on the neuropsychological tests immediately following injury. When compared to respective baseline measures, each mean score was significantly lower after sustaining the concussion. This study also proved the validity of the standardized assessment of concussion administered by certified athletic trainers on the sidelines. (McCrea, Kelly et al. 1997) A study conducted by the U.S. Naval Academy among their football players found SAC to be a very practical and efficient tool in assessing and monitoring concussions. The SAC is popular among the certified athletic training population for assessing concussions due to the convenience, low cost, practicality, and time efficient qualities it poses. A survey revealed that 85% of certified athletic trainers who replied to the survey believe that SAC aids in confirming an athlete has sustained a MTBI. (Ferrara, McCrea et al. 2001) A SAC database does exists that can be analyzed for trends, norms, and numerous other components of concussion. (McCrea 2001) With further development of the SAC, it will allow the classifications of MTBI's to be structured more definitively.

Interpreting the results

Controversy has arisen over interpreting the scores from the neuropsychological tests. It has been stated that neuropsychologists are the medical professional that infer the actions to be taken with the patient. (Randolph, McCrea et al. 2005) However, the reality of cost and accessibility of having a neuropsychologist in most instances is impractical and unrealistic. As a result, the development of computerized neuropsychological testing has become more efficient and effective in establishing this method in MTBI evaluation. (Lovell and Collins 2002) Much of the neuropsychological testing has evolved into computerized testing. These computerized tests have been proven to have much more sensitivity than the traditional neuropsychological tests. (Bleiberg, Halpern et al. 1998; Randolph, McCrea et al. 2005) Specifically, the computerized complex reaction time based tests are able to determine reaction time to the milliseconds. (Bleiberg, Halpern et al. 1998)

It is imperative that with neuropsychological testing, baseline measurements are collected to accurately assess the deficits and improvements in cognitive functions. (Maroon, Lovell et al. 2000; Echemendia, Putukian et al. 2001; Erlanger, Saliba et al. 2001) Each player scores differently on the various tests; therefore, it is crucial for comparison purposes to have scores that are deemed the 'norm' for that particular individual. Reliable change index (RCI) is a way for clinicians to compare an athlete's performance on tests after suffering to baseline taking reliability and practice effects into account and see if the differences in scores are significant.

The Concussion Resolution Index (CRI) is a web-based program that provides a battery of neuropsychological test focused on addressing practice effects, time constraints, cost, and expertise of interpretations. The web based program reports athletes' symptoms and MTBI history. Analysis of validity has proven the CRI indices are similar to traditional neuropsychological tests. (Erlanger, Saliba et al. 2001) A study conducted using the CRI in over 14 teams and institutions revealed that those athletes who had MTBI's had a statistically significant cognitive test result of three or more neuropsychologic symptoms, or both. In the 26 concussed athletes tested, 12% were withheld from activity due to the scores on the cognitive performance solely. These same athletes would not have been withheld from activity or identified as having an MTBI if the clinician based his/her evaluation solely on the symptoms reported by the athlete.

The Automated Neuropsychological Assessment Metrics (ANAM) is a computerized battery that measures cognitive function using various tests. This program has been utilized by various military personnel, professional sports teams, and various institutions from schools to hospitals and research centers. (Levinson and Reeves 1997) It is composed of six subsets: Matching to Sample, Mathematical Processing, Spatial Processing, Sternberg Procedure, Simple Reaction Time, and the Continuous Performance Test. (Bleiberg, Cernich et al. 2004) The battery is completed in roughly 20 minutes and records a throughput score. This score incorporates both the accuracy and speed at which the subject answers the questions. (Bleiberg, Cernich et al. 2004) The Sternberg memory search (MS6) focuses on reaction time combined with information processing. In addition, short term and visual memory is assessed on this subtest. The subject is presented with a set of letters, remember them and then identify them at a later point. (Levinson and Reeves 1997)

The Mathematical Processing (MTH) focuses on simple arithmetic that uses twenty-five three digit problems. The subject must subtract the two numbers presented on the screen and determine if the resultant value is greater than or less than five. (Levinson and Reeves 1997) The Spatial Processing module presents the subject with histograms and asked about the visual characteristics of them. The athlete is shown the histogram and then another histogram is displayed that is rotated from the original and the subject must determine if it is the same histogram or not. (Levinson and Reeves 1997) Procedural Reaction Time (PRT) focuses on matching to sample, encoding and responding. (Levinson and Reeves 1997)

Studies conducted comparing cognitive performances between normal healthy individuals and individuals that have suffered some trauma to the brain have been using ANAM. (Levinson and Reeves 1997) Studies conducted by Bleiberg et al have validated and shown accuracy of ANAM for the specific tasks measured in the battery. ANAM has been found to be very sensitive to subtle changes in neurocognitive function as a result of trauma to the brain. (Levinson and Reeves 1997; Bleiberg, Halpern et al. 1998; Bleiberg, Cernich et al. 2004) In addition, ANAM has proven to detect neurocognitive changes in patients suffering in the early stages of Alzheimer's disease. (Levinson, Reeves et al. 2005) This study found that of the 16 elderly patients measured, the data analysis revealed a significant impairment on the ANAM general indicator of brain function. (Levinson, Reeves et al. 2005)

Neuropsychological tests show deficits in cognitive functioning within two hours of injury and even up to months later. A majority of scores decline between the two hour and 48 hour window of time. (Echemendia, Putukian et al. 2001) Testing in this manner will allow the medical professional quantify just how severe the decline is and whether or not it warrants further medical attention.

Neuropsychological testing is a useful tool to aid in clinical diagnosis and management of MTBIs. (Lovell and Collins 2002) Team physicians in the National Football League have found neuropsychological testing essential in managing more severe concussions. At this point research has shown that it is the most sensitive tool in measuring cognitive dysfunction after a MTBI and most helpful in regards to RTP decisions. (Cantu 2001)

Neuropsychological testing allows the medical staff to quantify neurocognitive processing. (Pellman, Lovell et al. 2004) There has been research to examine a tool used to aid in the RTP decision that would be as sensitive as the computerized neuropsychological tests that exist for cognitive functioning. The computerized or paper-pencil methods of neuropsychological testing do not take into account functional impairment. Therefore, further development is needed in this area of return to play criteria. (Johnson et al. 2001) A study conducted looked at the ability of a subject to perform two separate tasks and then a dual task to see if any deficits occurred with the dual task in comparison to the individual tasks. (Broglio, Tomporowski et al. 2005) It was found that balance affected the subjects' reaction time of performing a set task. (Broglio, Tomporowski et al. 2005) Along similar return to play measures, a study conducted testing the sensitivity of the Cybex Reactor had 84 competitive athletes volunteer to perform a reactive functional assessment before and after sustaining a MTBI. The results found that the Cybex Reactor was unable to detect the subtle deficits that the athlete residually suffers from. (Johnson et al 2001) Therefore, a more sensitive or valid test needs to be developed to improve return to play decisions.

Despite the clarity it has brought to evaluating MTBI and returning athletes to activity, there is still hesitation in solely relying on neuropsychological testing in evaluating a MTBI. There is not one computerized battery of neuropsychological tests that fulfill all the criteria to be a valid, reliable test that would detect deficits in neurocognitive performance after mild trauma to the head. (Randolph, McCrea et al. 2005) There have been some studies conducted that have shown athletes with no deficits in scores when compared to baseline but have reported MTBI symptoms. Clearly, further research is needed in the area of neuropsychological testing.

Postural Stability

Trauma to the head causes changes in various parts of the brain thus, affecting the function controlled by that structure. It has been seen that injuries to the head often affect the cochlear and vestibular components of the brain. The cerebral cortex, cerebellum, basal ganglia, brainstem and spinal cord all play vital roles in postural stability. The basal ganglia is the first structure to receive joint position sense while the cerebellum coordinates motor impulses and the signals are sent to the motor neurons through the brainstem. (Broglio, Guskiewicz et al. 2004; Broglio, Tomporowski et al. 2005) The control center for balance and coordination is the cerebellum. The cerebellum is responsible for the coordination of learning and controlling posture and balance as it gets information from other parts of the body. (Guskiewicz 2001) Postural stability involves visual, somatosensory and vestibular information cohesively working fully. Athletes suffering from a MTBI have disruption in the communication of these three systems. This inability to receive and relay input causes postural instability in any direction. (Guskiewicz 2001) Trauma to the head can cause an inability to organize sensory information needed for balance. When visual cues are diminished or there is an unstable surface a person is unable to maintain postural stability if suffered from head trauma. As a result, the cerebellum is unable to accurately detect the current position of the body and gives the wrong signals to the brain stem which in turn causes improper and unnecessary motor patterns to engage inefficient posture. (Broglio, Guskiewicz et al. 2004) There has been research which proves a correlation with postural stability and noticeable deficits post concussive injury. Guskiewicz has shown that among collegiate and high school football players this domain of testing post concussion is sensitive to trauma in to the brain. Decrease in neuromotor ability has been shown in the initial three days following a concussion. A study looking at subjects who had suffered a mild head injury or whiplash injury and placed through a balance test showed significant anterior-posterior movements when compared to healthy individuals. (Rubin, Woolley et al. 1995) Another study conducted focusing on young children (mean age of 11.7 years) found posturography was significantly disturbed in those children tested immediately after mild head trauma when compared with control subjects. (Lahat, Barr et al. 1996)

Measuring Postural Stability

Multiple methods to assess postural stability have been used throughout various research studies. A measure recorded from a force plate in which the subject is standing on is one method commonly used. Balance Error Scoring System (BESS) is a convenient and cost effective method to assessing postural stability and can be utilized immediately after insult in a game, practice situation. The BESS is a clinical measure of postural stability involving six variations of the Rhomberg. Three are performed on a stable surface while the other three are on an unstable surface. It is calculated by adding a point for each error during each of the six 20-second tests. Types of errors include lifting hands off the iliac crests, opening of eyes, taking a step, stumble, or fall moving greater than 30 degrees of hip abduction, lifting of the forefoot or heel of the ground, and/or remaining out of the test position for greater than 5 seconds. Various professionals regard the ‘gold standard’ to measuring postural stability to be the Sensory Organization Tester. This instrument incorporates three sensory systems of visual, vestibular and somatosensory into the various testing conditions and is thus able to detect differences in the subsystems of balance. (Peterson, Ferrara et al. 2003) The protocol eliminates and creates confusion among the various systems. In consists of a force plate that measures the change in the subject’s center of gravity. Six different conditions are administered. The first, the force plate and the surrounding walls remain stationary; the second condition the subject stands with his or her eyes closed while the force plate and surrounding walls remain stationary. The third condition requires the athlete to have his or her eyes open and the force plate remains still while the surrounding walls shift away from the subject. The fourth condition the athlete has eyes open and the surrounding walls remain stationary but this time the force plate tilts in the anterior and posterior direction. The fifth condition requires the athlete to have the eyes closed while just the force plate tilts in the anterior and posterior direction. The last condition has the athlete with both eyes open while the force plate and surrounding walls move simultaneously. (Guskiewicz, Ross et al. 2001) The scores that are reported include: equilibrium score measures center of gravity sway under each condition; sensory analysis ratios identify impairments of the individual sensory systems; strategy analysis measures the amount of movement that occurs at the ankles and hips while the person balances; and center of gravity measure that determines how much deviation from the original COG that the subject has moved throughout the trial.

There are newer testing modules that are being studied which incorporate both a cognitive and motor task. When determining if an athlete is ready to return to play, often he or she will be out through various testing that does not closely relate to his or her sport. The dual task testing is thought to better replicate the functions of the brain during activity. It was found that those subjects who participated in the study had better postural control when performing the dual task.

Graded Symptoms Checklist

The graded symptom checklist cannot be the sole decision making piece of information to determine whether a player has a concussion or not. Players often do not report symptoms for a multitude of reasons. (McCrea 2001; Collins and Hawn 2002) A study conducted among Canadian football players found that slightly less than half of the players had suffered the symptoms of a concussion during the season but only 18.8% reported those symptoms to their athletic trainer because they realized that they had a concussion. Nearly 70% of concussed players experienced more than one concussion per season. (Delaney, Lacroix et al. 2000; Echemendia and Julian 2001) It has been reported in the literature many return-to-play decisions have been based upon the athlete's self-reported symptoms which typically resolves in three days or less when neurocognitive deficits are present at least seven days after injury. (Field, Collins et al. 2003) The validity of the GSC has been studied and evidence is there to support it. The evidence shows strong validity of the test and addressed earlier limitations about sample size. (Piland, Motl et al. 2006)

Return to Play

The various grading scales, graded symptom checklist, neuropsychological, postural assessment, as mentioned above are all components of the return to play criteria. Standardized assessment evaluation methods are more commonly used by ATC's versus routine clinical examinations. (McCrea 2001) Determining the severity of the athlete is vital when managing the athlete and predicting how long the athlete will be out of activity however, ultimately the various components of the initial evaluation will be compared to the new results to determine if the athlete is ready to get back.

Prevalence in Football

Mild traumatic brain injuries are inherent in the sport of football. A full contact, high intensity sport, football puts the athlete at a higher risk of sustaining a MTBI. This is due to the sheer number of exposures that the athlete receives during any given practice or game situation. The contact in football far outweighs that experienced in sports such as field hockey, basketball, soccer, volleyball, tennis, gymnastics and the many other sports people participate in. Mild traumatic brain injury has become an increasing entity in the football arena. Football has the greatest amount of participants in the U.S., thus MTBI are more common in high school and collegiate football. The NATA reported football with the highest incidence of MTBI among high school sports over a three year period. (Powell 2001) In this study, football accounted for 63% of MTBI among ten sports tracked. (Powell and Barber-Foss 1999) Acceleration-deceleration forces are common with tackling and blocking. (Bailes and Hudson 2001) An estimated 1.5 million compete in football alone which increases the amount of exposures each person can have. (Gerberich, Priest et al. 1983) Another study published by the NATA reported a head injury rate of 0.59 per 1000 athletic exposures of which, football players represents two thirds of this statistic. (Gebke 2002) Concussions are just as prevalent at the professional level as 100-120 concussions are documented each year.

Schneider studied and analyzed the incidence of MTBI in football and as a result changes were made in protective head gear, resulting in the switch to football helmets are made with a hard protective outer shell versus the old leather helmets used in the beginnings of the sport. (Bailes and Cantu 2001) The National Operating Committee for Safety in Athletic Equipment (NOCSAE) set a standard that all football helmets must meet. Certification of football helmets began in 1975 must be recertified each year and is backed by the NCAA and the National Federation of State High School Associations. (Bailes and Cantu 2001) Aside from equipment changes in the sport of football, changes in the rules of the game have come as a result of research conducted in regards to MTBI. 1976 saw an implementation of new rules to the game.

A study was conducted comparing impacts to the head in football players, hockey players and soccer players in which each was fitted with accelerometers in the helmets each adorned. An offensive and defensive were analyzed in this particular study. The offensive lineman experienced the most extreme head acceleration during a blocking drill, while the defensive lineman experienced the peak during tackling a running back. During the game were data was collected, there was an average of 40.5 impacts per player per hour with an average peak acceleration of 29.2 ± 1.1 g. This study mentioned a theoretical impact threshold of 200g. (Naunheim, Standeven et al. 2000)

National Football League

An effort made by the National Football League to learn more about MTBI put together a committee on this topic. This committee lead by Elliot J Pellman has conducted a large scale study over a six year period to analyze multiple aspects of MTBI. Eleven manuscripts have been published thus far, each focusing on a different component of MTBI on professional football players. In a number of the studies published the methodology consisted of analyzing network tapes of NFL games and replication of those studies in a laboratory setting.

It was found that a majority of the impacts resulting in concussions occur from the facemask. More than half of the impacts were from another player's helmet and it was generally the player being struck that sustained the MTBI. Quarterbacks were found to have the greatest risk of MTBI with wide receivers and the offensive and defensive were least susceptible to suffer from MTBI. Severity Index, Head Injury Criterion, peak translational acceleration and head velocity change all impact the severity of the MTBI. (Pellman, Viano et al. 2003) The epidemiological aspect of the study found that out of the 787 reported cases of MTBI, the offensive unit experienced the most MTBI, more MTBI occurred in passing plays followed by running plays and the mechanism was tackling or being tackled versus blocking or being blocked. In addition the top three symptoms reported most frequently were headache, dizziness, and blurred vision. (Pellman, Powell et al. 2004) Multiple MTBI's resulted in higher somatic complaints in comparison to the first MTBI. More often players were withheld from competition for longer than 7 days if previous history of MTBI was present. (Pellman, Viano et al. 2004) Newman found that those players which sustained concussions had a greater maximum resultant linear and angular acceleration than those who did not sustain a MTBI. (Newman, Beusenberg et al. 2005) The study replicated 31 impacts and using Hybrids fitted with helmets equipped with nine linear accelerometer. Various measures of acceleration, linear and angular, were recorded from the reconstructions. (Newman, Beusenberg et al. 2005) Information and technology used in studies such as these have aided in the development a system being studied in select collegiate football programs in the nation.

Head Impact Telemetry System

The Head Impact Telemetry (HIT) System measures linear acceleration of the head. The system utilizes six dime-sized accelerometers placed in the helmet. The accelerometers are powered by a battery pack which also is housed on the accelerometer unit. The magnitude, duration, date and time, and impact location, are displayed on a laptop. The information is transmitted via radio signals from the accelerometer units to the laptop. This allows the researcher to gather real-time data which, it is theorized, could be helpful in identifying someone at risk for being diagnosed with a MTBI. In 2003, a study used the HIT System to record data from accelerometer units in 38 football helmets for ten games and thirty-five practices. Over 3,300 hits were recorded over the course of the season with an average of about thirty to fifty significant impacts. The average peak head acceleration was 32g ± 25 g, with an injury threshold of 95 g. It is important to note that this injury threshold was based on data from one concussion, measured at 81 g, and should be interpreted with extreme caution. Impact locations were found to be dependent on the position of the player as well as the technique he used to play the position. Wide receivers received more frontal impacts compared to linebackers that had more variability in the location of head impacts. (Duma, Manoogian et al. 2005) It is thought that the data collected and analyzed from the study being conducted may also help medical professional in diagnosing MTBIs as well as determining a standard RTP guideline. A number of studies are incorporating this helmet accelerometer technology, allowing clinicians and researchers to observe head impacts sustained by football players in real-time.

CHAPTER III

METHODOLOGY

Participants

Forty- three Division I male collegiate football players (20.74 ± 1.83 years old; 242.64 ± 41.02 kg, 73.41± 2.50 cm) (Table 1) were initially enrolled in this study. Subsequently, 24 players were used in the comparison of scores between impacts greater than 100 g and baseline, while 38 completed testing in the less than 70 g and baseline. Our sample included a variety of playing positions such as: defensive linemen (8 DL), offensive linemen (10 OL), offensive backs (12 OB) and defensive backs (13 DB). Subjects had no serious medical conditions or any serious injury to the lower extremity within six weeks of testing that affected their ability to perform balance tasks. Participants were required to fill out a medical health history questionnaire. Exclusion criteria included previous head injury within the last six months, or having a current vestibular, visual, or balance disorder. Participants underwent baseline testing prior to the start of the season. The participants were given an information packet with information about the study and what it entailed. All subjects signed the appropriate informed consent form that was approved by the institution of review board at The University of North Carolina (Appendix A).

Equipment

Head Impact Telemetry System

In order to identify players who had sustained a given impact magnitude, we used the Head Impact Telemetry (HIT) System (Riddell Corp.; Elyria, OH). The HIT System obtained data from units comprised of six spring-mounted single-axis accelerometers (Figure 1) embedded into selected Riddell VSR-4 and Revolution football helmets (Riddell Corp.; Elyria, OH). The signal transducer was linked to a laptop computer in the Sideline Response System (Figure 2) via radiowave transmission (903-927 MHz). The information was stored on an onboard memory system (up to 100 impacts) or was immediately transferred to the laptop computer system (8 bit, 10000 Hz/channel). Twelve milliseconds of data were stored prior to the impact as well as 28 ms after the impact. It had the ability to simultaneously monitor a total of 64 players. The downloaded impacts were then processed through a validation algorithm; variables such as peak head linear acceleration, impact location, Gadd Severity Index (GSI), Head Injury Criteria (HIC), sagittal and lateral peak rotational acceleration, were computed (Figure 3). The HIT System was previously validated in laboratory testing with Hybrid dummies equipped with football helmets. (Padgaonkar AJ 1975; DiMasi 1995; Duma, Manoogian et al. 2005)

Balance Performance

The Sensory Organization Test (SOT; NeuroCom International Inc.; Clackamas, OR) was used to assess participants' balance performance during preseason baseline screening, and in both follow-up test sessions. The SOT is able to assess balance performance by disrupting input from the visual, vestibular, and somatosensory systems. The participants stood with feet shoulder width apart on the force platform with arms comfortably at both sides (Figure 4). Participants were asked to complete three 20-second trials of six different sensory conditions in random order. The six testing conditions (Figure 5) were as follows: normal vision and normal support surface, eyes closed with normal support surface, sway-referenced visual input with normal support surface, normal vision and sway referenced support surface, eyes closed and sway referenced visual and support surface. The outcome measures represented how much that particular component (visual, vestibular, somatosensory is contributing to the overall composite score.

Neurocognitive Function

Participants were tested using the Automated Neuropsychological Assessment Metrics (ANAM) battery to assess neurocognitive performance. This computerized test battery focused on seven main sub-tests (Simple Reaction time 1, simple reaction 2, math processing, match to sample, sleep scale, procedural reaction time, code sub 9, memory search 6) (Figure 6). Although the participant undergoes testing of the various subtests of ANAM in the same order, the stimuli presented each time varied to limit practice effects.

Symptomatology

The Graded Symptom Checklist (GSC) is a self-reported symptom scale that assesses the presence of 18 concussion-related symptoms and severity using a seven-point Likert scale ranging from asymptomatic (0), to mild (1), to severe (6) (Figure 7). During our baseline evaluation, participants were instructed to rate the severity of any symptom they reported feeling at least three times per week over the course of the summer preceding the baseline test session. During follow-up test sessions, the participants were asked to rate the severity of their symptoms based on what they felt at that time.

Procedures

This was a double-blind, randomized study. The primary investigator was blinded from the test condition and the test results until the completion of the study. The participants were blinded from which condition each was being tested. The primary investigator performed the testing during the preseason baseline screening and during the follow-up test sessions. One of the co-investigators determined which players were to be tested on that particular day to ensure the primary investigator and players were blinded. Once the season was complete, clinicians trained in administration and evaluation of the tests interpreted the results. Random test administration order occurred during this study to remove possible effects of testing order (Table 2).

Preseason Baseline Evaluation

Each player who participated in the study signed an IRB consent form and a sheet explaining the purpose and procedures of the study. A medical health history questionnaire was given to each subject and each then got baseline tested, so that baseline measurements could be obtained, for balance and neuropsychological testing. Testing was conducted in the Sports Medicine Research Lab at The University of North Carolina prior to the start of the 2005 collegiate football season. Subjects were seated in a quiet room in order to perform the computerized neuropsychological testing using the ANAM. This testing procedure, consisting of seven modules, took about 20 minutes to complete. Balance performance was measured using the Sensory Organization Test (SOT). Directions were verbally recited to the athlete by the examiner prior to the start of test administration. The participant was asked to stand as motionless as possible in normal stance; feet shoulder width apart, for each trial. Testing lasted approximately 15 minutes. A Graded Symptom Checklist was also completed by the athlete in whom he reported and rated any symptom he is experienced at the time of test administration.

Post Impact Evaluation

Post impact sessions began two weeks prior to the start of preseason camp and continued until the completion of the fall season and resumed in the spring season to reach the desired number of subjects (Figure 8). Athletes were targeted by the co-investigator (JPM) based on the impacts they had sustained during the practice or game. The co-investigator targeted athletes that met one of the following criteria: they had sustained at least one impact greater than 100 g, or they had sustained no impacts greater than 70 g. Testing session order was randomized among the population. Testing (ANAM, SOT, and GSC) were carried out within 24 hours of the end of the respective session. The athletes were instructed to place their GSC into an envelope in order to blind the investigators from this information. Each test session lasted approximately 45 minutes to complete and once again, the order in which the participant completed the various tests was randomized. Once an athlete had been tested under one condition, they were not targeted for the other condition for a period no less than two weeks.

Data Reduction and Analysis

Outcome measures obtained from the SOT included an overall balance composite, as well as ratio scores related to somatosensory, visual, and vestibular performance. Each outcome measure was taken from the computer printout. The ANAM yielded throughput scores for each of the individual test modules which were taken from the database on the computer. The GSC was analyzed for both the total symptom score and the number of symptoms reported. The total symptom score was obtained by summing all the individual symptom scores in the GSC and the number of symptoms was obtained as well.

In order to answer our first research question, we performed a within-subject repeated measures analysis of covariance (ANCOVA) on each outcome measure while covarying for the number of impacts greater than 70 g the participant had sustained since the beginning of the season and within the seven days leading up to the session in which they sustained an impact greater than 100 g. Other repeated measures ANCOVA, while controlling for the same two covariates, were performed on our outcome measures in order to assess the second research question. An alpha level of .05 was set prior to analysis and data was analyzed using SPSS for Windows Version 13.0 (SPPS, Inc.; Chicago, IL).

CHAPTER IV

RESULTS

A total of 43 Division I collegiate football players completed the baseline and at least one follow-up test session: 24 participants completed the high testing condition and 36 participants completed the low testing condition. Twenty-two participants were able to complete both testing conditions. The results we observed for measures of balance performance, neurocognitive function, and symptomatology are detailed below.

Balance Performance

Results from our balance performance assessment are provided in Table 4. In assessing our first research question, we did not find any statistically significant differences in balance performance scores following an impact of 100 g. This was true for all our outcome measures, including an overall composite score ($F_{(1, 24)}$=.015, p=.905)(Figure 10), somatosensory ($F_{(1, 24)}$=.065 p=.801)(Figure 7), vestibular ($F_{(1,24)}$=.126, p=.727)(Figure 8), and visual ($F_{(1,24)}$ = .101, p=.754)(Figure 9) ratios. For our second research question, a statistically significant difference was observed for the vestibular ratio ($F_{(1,36)}$=.8.677, p=.006)(Figure 11) and composite ($F_{(1, 36)}$=2.482, p=.124)(Figure 12). There were no observable differences in the somatosensory ($F_{(1,36)}$=1 p=.325)(Figure 13), and visual ($F_{(1, 36)}$ = 4.052, p=.052)(Figure 14) ratios.

Neurocognitive Performance

Following an impact greater than 100 g, we observed a statistically significant difference from baseline in the MTH module of ANAM ($F_{1, 24}$=17.04, $p<.001$)(Figure 15). In response to our first research question, there were no other observable differences in the ANAM modules: SRT1 ($F_{(1, 24)}$=.492, p=.491)(Figure 16), SRT2 ($F_{(1, 24)}$=.009, p=.927)(Figure 17), MSP ($F_{1, 24}$=.498, p=.488)(Figure 18), PRT ($F_{(1, 24)}$=1.43 p=.245)(Figure 19), CS9 ($F_{(1, 24)}$=.027, p=.87)(Figure 20), and MS6 ($F_{(1, 24)}$=.087, p=.771)(Figure 21). Following a session where a head impact no greater than 70 g was sustained, statistically significant differences in the MTH ($F_{1,36}$=10.584, p=.003)(Figure 22), SRT1 ($F_{(1, 36)}$=6.012, p=.02)(Figure 23), CS9 ($F_{(1, 36)}$=4.836, p=.035)(Figure 24), and MS6 ($F_{(1, 36)}$=.5.402, p=.026)(Figure 25) modules of ANAM were observed. No observable differences, in response to our second research question, were observed for the SRT2 ($F_{(1, 36)}$=.943, p=.338)(Figure 26), MSP ($F_{(1, 36)}$=2.129, p=.154)(Figure 27), and PRT ($F_{(1, 36)}$=.758 p=.39)(Figure 28) modules of ANAM. Finally, there were no differences observed with the low condition comparison SS ($F_{(1, 36)}$= 3.77, p=.061), a subjective measure of cognitive fatigue assessed at the end of the ANAM testing protocol.

Symptomatology

Two subcomponents of the graded symptom checklist were analyzed, the total number of symptoms reported ($F_{(1, 24)}$ =3.540, p=.075)(Figure 29), ($F_{(1, 36)}$ =1.4, p=.245)(Figure 30) and the total severity of symptoms reported ($F_{(1, 24)}$ =.209, p=.652)(Figure 31), ($F_{(1, 36)}$ =.001, p=.977)(Figure 32). The data analysis revealed the scores were relatively similar among the testing conditions and there were no statistically significant differences present.

Absolute Means versus Adjusted Means

Absolute means were compared with the adjusted means used for the ANCOVA's and there was little difference between the two values for each outcome measure. Both means were examined to detect if there was more clinical significance with the differences found and whether the absolute means illustrated the statistically significant differences between the various impact condition and testing parameters better than the adjusted means but found the numbers were exceedingly analogous.

CHAPTER V

DISCUSSION

The purpose of this study was to examine the effects of impact magnitude on the immediate performance of balance, neuropsychological functioning and symptomatology despite no clinical diagnosis of a MTBI. This study was the first to collect real time data on collegiate football players and compare clinical outcome measures between high and low impact conditions. Finding the exact mechanism of MTBI is needed in order to address prophylactic measures relevant to the medical profession. A number of studies have investigated various biomechanical aspects of concussions in football; however, the majority of these studies have been in a laboratory setting using hybrid dummies. Some authors (Pellman, Viano et al. 2003; Zhang, Yang et al. 2004) have proposed an injury threshold, but these thresholds have not been confirmed through controlled field studies. The first study to investigate real-time impacts in collegiate football players was conducted using fewer subjects than used for this study. Duma et al. reported an average linear acceleration of 32 ± 25 g that did not result in concussion in 38 players whereas Pellman (Pellman, Viano et al. 2003) reported 60 ± 24 g in non-injured football players. (Duma, Manoogian et al. 2005) Mihalik et al (Mihalik 2005) documented from data collected from the fall 2004 football season using the HIT System, players on average received impacts to the head around 19.46 ± 2.29 g. He reported a maximum average impact of 199.98 g with the highest impacts typically being recorded during practices. (Mihalik 2005) This information combined with the findings from this study perpetuates the need for a better understanding of impact biomechanics during participation in football. Various magnitudes have been reported in the literature to cause concussive injuries. Pellman et al has reported that a suspected injury threshold of 75-90g's to the head. Duma reported 25 impacts greater than 98 g, none of whom had a concussion, further questioning the speculated threshold however, the issue of underreporting was mentioned as a possible explanation of those findings. Pellman et al. have investigated the biomechanics of improved helmet structures, biomechanics of the striking player and the results of concussion. These studies have been conducted in the laboratory and have limited field relevance. (Pellman 2003; Pellman, Viano et al. 2003; Pellman, Viano et al. 2003; Pellman, Lovell et al. 2004; Pellman, Powell et al. 2004; Pellman, Viano et al. 2004; Pellman, Viano et al. 2004; Newman, Beusenberg et al. 2005; Pellman, Viano et al. 2005)

This study was conducted in an attempt to determine the efficacy of using helmet telemetry to identify concussion and/or concussion-like signs and symptoms in the absence of subjective information provided by the athlete. The results of this study revealed no major differences between the two impact magnitude conditions when compared to baseline measures, thus refuting our first research hypotheses. In addition, this study also raises questions about the validity and clinical significance of those studies conducted by Pellman, Zhang, and Newman. Questions about a much higher injury threshold are raised, as are the role that other factors in an impact to the head might play to causing a MTBI, are raised.

A study conducted at Wayne State (Zhang, Yang et al. 2004) investigated an injury threshold and found that rotational and translational acceleration were the most important factors in the severity of the presence of a MTBI. (Zhang, Yang et al. 2004) The study did not use real life subjects, rather brain models created with synthetic materials replicated to be just like a cadaver brain and skull, was able to look at the effects impacts had to the brain itself, not just the skull. The basis of the threshold is gathered from a study conducted in the laboratory, using game film to recreate the impacts and on models that are not exact to the players head in the video. The threshold was examined from a physiological perspective versus this study done which examined real field situations and effects on test measures of balance and neuropsychological functioning. It may be that the theoretical threshold speculated by Zhang et al. has effects and causes changes in the structure of the brain microscopically but does not effect the gross motor skills tested in the various MTBI batteries. Perhaps the single measure of linear acceleration was not enough of a predictor, or a different predictor than the rotational and translational acceleration mentioned in the Wayne State study. The linear acceleration associated with the combination of the rotational and translational may be significantly higher as proven by this study. The suspected threshold of 98 g should be reevaluated and if the injury threshold is in fact much higher, than there would be no decline in the scores we gathered for balance, neuropsychological and symptomatology at the current level.

SOT Measures

Balance was not largely affected by the magnitude of the impact to the head. The low impact condition actually resulted in an increase in balance performance (composite and vestibular) when compared to baseline scores. The visual component of the SOT in the low impact condition was approaching significance, thus marking an increase in balance performance. However when looking at the outcome measures, the effect sizes are so small that the difference is negligible from a clinical perspective. This study investigated players that did not self-report symptoms to the certified athletic trainer and were not clinically diagnosed with a concussion. The majority of published studies have reported that balance performance is affected in athletes diagnosed with concussion. (Levinson and Reeves 1997; Guskiewicz 2003) The increase in balance scores in the pool of participants that took part in the study could be for a number of reasons. These participants were not clinically diagnosed with a MTBI; therefore changes should not be expected to be seen. The sheer magnitude of the impact the players took was not of a value that it affected the various components of the vestibular and somatosensory system. The studies conducted by Pellman, Zhang and Newman did not look at test measures as a result of the impact rather, took those that were diagnosed with a MTBI and recreated the impact. The authors conducted the study as impact magnitude being the sole predictor of the concussion, rather than taking other aspects of concussion into account.

If the low impact testing condition resulted in significant improvements in balance performance, as a clinician, one should question the lack of improvement in the high impact condition. Since random testing order occurred, it negates the effects of learning. If it is natural to have an improvement on balance performance as the duration of training continues, then a lack of one with the high impact condition might indicate a clinical significance to the medical professional.   A study conducted by Mrazik et al. looked at the effects of severity of injury on various parametric measures and found some variation in balance testing. There were no significant trends seen in the various sub-components of the SOT measures. All tests were taken at least 24hrs. post injury whereas our study performed the testing within the first 24 hrs. of the session in which he sustained the impact. This same study found that the player who sustained a grade I concussion had virtually no deviation from baseline measures, thus confirming that the magnitude of the impact may not be the sole determinant of a MTBI. This information suggests that balance performance cannot be the only factor the clinician uses to determine return to play.

Neuropsychological Measures

Significant differences were observed between baseline and the low testing condition on the ANAM battery. The most obvious decline in performance was observed for both the Simple reaction time-1 and Code substitution subtests, suggesting that reaction time and delayed memory are negatively affected following the day in which the players experienced no impacts greater than 70 g. Improvements in performance observed in Procedural reaction time, and Memory search-6 are difficult to explain. The inconsistencies among the change in scores could have been a result of any number of unforeseen and uncontrollable variables. For example, similar to the SOT outcome measures, the effect size is small leading us to find little clinical significance. The study conducted by Mrazik et al. as mentioned above found that the individual who was diagnosed with a grade I concussion actually had an improvement from baseline scores on the first post-injury evaluation, and the overall test results showed virtually no impact of the MTBI on his performance in the various tests. (Mrazik, Ferrara et al. 2000) In the other two cases of MTBI, even the more severe cases, the athlete surpassed the baseline measures on that particular individual. Peterson et al. also concluded that group mean comparisons on the various tests to determine if the scores are at the baseline values, may not be the best indicator of return to play decisions. (Peterson, Ferrara et al. 2003)

In addition, it has been reported in the literature that learning effects are found with repeated use of the ANAM battery that cause perhaps a false sense of improvement in scores on the ANAM.(Levinson and Reeves 1997) The study conducted by Levinson and Reeves had the subjects retaking the test every two to three months as opposed to the typical serial testing that occurs in sports medicine. Practice effects are a valid limitation of neuropsychological tests. The amount of practice effect that has been incurred depends on the nature of the test, the time period of testing, and how many times the subject is tested.(Echemendia and Julian 2001; Grindel, Lovell et al. 2001) Practice effects can alter the course of action that the athlete should be receiving. An athlete has the potential to improve the scores from the baseline battery due to these practice effects. Most research has also shown that these practice effects are null and void after a period of two weeks but in some cases may last upwards of seven weeks. This study mandated a two week ‘buffer period’ to allow at least two weeks in between test session one and test session two. This two week period was an effort to eliminate the practice effects experienced with ANAM. In addition to the learning effect between each session, it was later found out that the incoming freshmen were given a similar battery to test for learning disabilities by the academic center. This administration of a test of this nature further perpetuates the learning effect.

Another confounding variable to consider when interpreting improvements on the ANAM scores should be the effects of attention deficit disorder (ADD), a learning disorder which was prevalent in a significant number of our subjects (DO WE KNOW A NUMBER or % TO ADD HERE?). The variability of this learning disorder and how the outcome measures of ANAM are altered has historically been avoided. The effects of this disorder may help explain why there was in fact an improvement. Often athletes are medicated for ADD and typically only take their medicine to focus on academics. During the summer, a majority of athletes do not take their medication since most are taking a reduced course load if any. Baseline measures are taken during the summer, generally during that time period that the athlete is not taking the prescribed medication. Thus, when the athlete retakes the test during the season, the athlete is medicated and as a result, is able to better focus. However, this gray area is one that warrants further study so that we might better understand the full repercussions of ADD on neuropsychological tests.

Other test results have been shown to discern the minute deficits in neurocognitive functioning that occurs with concussion. (Lovell 2002) Different types and severity of concussions have been documented to have different results in symptom reporting and neuropsychological testing. Echemendia et al. discussed the differences in concussions and how some do not disturb those parts of the brain that affect the results of neuropsychological tests. (Echemendia, Putukian et al. 2001) Instead, the athlete may demonstrate deficits elsewhere or be extremely symptomatic. They also state that neuropsychological testing is not as sensitive as clinicians typically need it to be, although still represents the best tool athletic trainers have to assess deficits following concussion. (Echemendia and Julian 2001)

GSC measures

The main purpose of this study was to see if there were deficits in balance and neuropsychological function in the absence of self reported symptoms. Underreporting is a global problem when dealing with MTBI and looking at other ways to identify people who have suffered from an MTBI without their self report was of great interest to the primary investigator. Our analyses showed no significant difference between the two testing conditions and baseline with symptom reporting or severity of symptoms reported. These players had received a significantly higher magnitude impact to the head and even within 24 hours they still were symptom free relative to pre-season baseline measures. It has been long thought that a hard hit to the head would result in a concussion however; this study suggests that the magnitude is not the only factor in predicting a concussion. As clinicians, we often rely on the athlete to be honest with us when dealing with a concussion. Our results support the notion that if an athlete is symptomatic, he or she will be unable to do the activity without having those symptoms interfere.

It has been stated in literature that self-reported symptoms should never be the sole determinant of a concussion. As stated earlier, football players compete in a demanding and intensely physical environment where many players have little knowledge about the physiological reaction as a result of impacts to the head, the concussive cascade, and their disposition later in life as a result of repeated impacts to the head. (Kaut, DePompei et al. 2003) Underreporting is a large and prominent issue in dealing with concussions. (Lovell and Collins 1998; Echemendia and Julian 2001; Collins and Hawn 2002; Field, Collins et al. 2003; Kaut, DePompei et al. 2003) The nature and environment of the sport breeds the growing problem of underreporting.

Football players have become accustom to symptoms that are commonly associated with concussions. Athletes often learn to expect these symptoms from the nature of their sport and do not think they are abnormal. Many of the athletes had difficulty distinguishing what symptoms were appropriate to indicate because they did not feel it was due to the impact sustained, rather the norm of how they should feel at the end of a hard practice. One study documented that half of the participants did not understand the correlation of symptoms to a head injury. (Kaut, DePompei et al. 2003) A study conducted by Macciocchi found the most common symptoms reported in concussed individuals were headache, dizziness, and memory problems. (Macciocchi, Barth et al. 1996) A study conducted by Kaut et al. found that 30% of athletes reported receiving a direct blow to the head that resulted in dizziness, proving to be the highest frequency of symptoms reported by football players (35%). A study conducted by Erlanger et al reported 12 % of subject pool would not have been identified as having a concussion if based solely on self-reported symptoms. He sampled a group of concussed athletes that underwent CRI evaluation and the scores revealed deficits in cognitive functioning among all the subjects. (Erlanger, Saliba et al. 2001)

Symptoms have been shown to resolve before balance and neurocognitive functioning return to normal.(Collins, Grindel et al. 1999; Echemendia, Putukian et al. 2001; Field, Collins et al. 2003) Another study found that high school and collegiate football players reported fewer symptoms five to seven days post concussive injury than they reported on their baseline measures. (Field, Collins et al. 2003)

The ability of the program to determine the various components of the impact such as time, location, duration, magnitude and history of hits to the head is important because in the future that particular information may be a key criteria needed to identify those players that may have suffered a concussion. Football historically has been known to view loss of play due to a concussion as a sign of weakness. With this mentality, many inherent risks are present in this sport and many injuries are treated each year.

Future Direction

With the vast technology that has and continues to be created, much more field data will be required before we fully understand the best utilization of these methods and results. With these data, researchers can learn more about the specific biomechanics of impacts in football to the head. Analysis of impact location, number of impacts, previous history, and position may play a significant part in determining the threshold magnitude of a concussion. With more information about impacts to the head, strides will hopefully be made to prevent concussion & to make more sound return to play decisions following concussion. Research must determine a way to improve early recognition of those players susceptible to concussive injuries. Once the recognition and the preventative component have been determined then research about return to play can be more easily tackled. Improvements in helmet design and tackling techniques need to be addressed once the research provides the data to support the efforts. Education and getting the players involved is vital to further research in this area. Throughout the course of this study players had little interest or desire to take part in a study that would benefit them based on their participation. Football players underreport concussions because of the seriousness with which the medical staff appoints to them, however, the players make no effort to learn how to avoid getting a concussion in the first place. The more research that is conducted in the field on actual football players in addition to those tests conducted in the laboratory, the more athletic trainers will be able to effectively educate their athletes.

Limitations

Due to time conflicts, subject compliance and injuries suffered throughout the season, all 43 players that were baselined were unable to complete both test conditions. Throughout the data analysis many measures were approaching significance but perhaps due to the small sample size, that significance was not reached.

The 16-24 hour window in which the players were tested was possibly not early enough to identify deficits that would have been present immediately after the impact. However, as previously stated, underreporting is extremely frequent in football thus; a majority of players would not have reported their symptoms to the ATC until the next day. Due to the desire to replicate a realistic situation in the field, the time window in which the testing was done in was clinically practical. At the University of North Carolina- Chapel Hill, the normal protocol for testing concussed athletes is to wait until they are at least asymptomatic. The earliest that this would typically occur is 16-24 hours after the impact.

Much is unknown about many components of concussions and the concept of an injury threshold existing is speculation. The results from this study raise more questions as to what other important components must be analyzed to see how the "pieces of the puzzle" in the mechanism of injury for a concussion fits together.

Clinical Significance

This study has resulted in new and important information regarding the most predictive factor of an impact that results in a MTBI. This was the first field study to really examine the theoretical concussive injury threshold in actual live subjects in real-time situations on various concussion testing protocol. Surprisingly, there were little to no acute deficits seen after an impact greater than a 100 g to the head and improvements seen in testing parameters with impacts below 70 g. The results on the neuropsychological test battery support the statement that there need not be a deficit in scores from baseline to indicate a MTBI, rather an absence or reduction of learning effects can be just as conclusive that the subject has a concussion. The finding on the symptomatology emphasizes the importance of the athletes' self-reported symptoms. If the athlete receives a high magnitude impact and does not have any symptoms associated with a concussion, then we are less likely to assume that he or she has in fact suffered a concussion. The clinician should make an effort to inquire about symptoms with an athlete who has taken a 'hard hit' not just immediately, but within 24 hours of the impact. The findings with the balance scores support evidence in the literature that the vestibular and visual components of balance are the most sensitive to trauma and will be the first to show changes in score. As clinicians, if a MTBI is suspected and sophisticated technology is unavailable, then giving the athlete a task that challenges the visual and vestibular components of balance should aid in the assessment of MTBI.

Anecdotally, there have been several cases in which players have been diagnosed with concussion after a moderate magnitude impact (approximately 60-70 g). Three players in particular have received impacts below the 98 g threshold. These particular cases illustrate that the theoretical concussive injury threshold is not the sole predictor of injury as previously speculated and many other factors may play a role in the effect of the magnitude impact on causing a concussive injury.

Contrary, we have had numerous players receive a plethora of impacts with a magnitude greater than 100 g that have had no clinical symptoms of a MTBI. This study highlighted the clinical evidence that there were no statistically significant decreases in the various outcome measures that is used to help solidify the diagnosis of a MTBI. Bleiberg concurs with Collins that cognitive deficits as a result of a MTBI not always need to be in the form of a decrease in scores when compared to baseline scores but rather an absence or reduction of practice effects in the various outcome measures. (Bleiberg, Cernich et al. 2004) This study does support the notion that a lack of practice effects may signify a deficit due to the impact magnitude. However, having said that and looking back at the anecdotally evidence, magnitude may not be the sole predictor of the mechanism of concussions.

Examining the frequency of impacts that had a magnitude greater than 100 g, one can conclude it is very diminutive. The majority of the impacts sustained by the football players in this study were well concentrated in the lower ranges of impact magnitudes. Nearly ninety percent of the impact magnitudes recorded over the time period of the study ranged from 10 g-70 g. This range should alert the certified athletic trainer that a majority of the impacts players receive are not of the higher accelerations (>80-100 g) believed to cause concussion.

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APPENDIX A

Informed Consent

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

Medical IRB Study #04-EXSS-366
Consent Form Version Date: August 6, 2004

Title of Study: Prospective investigation of sport-related concussion: relationship between biomechanical, neuroanatomical, and clinical factors

Principal Investigator: Kevin M. Guskiewicz, PhD, ATC
UNC-CH Department: Exercise and Sport Science
Phone number: 919-962-5175

Co-Investigators: Keith Smith, MD, PhD; Weili Lin, PhD; Mario Ciocca, MD; Stephen Marshall, PhD; Daniel Hooker, PhD, ATC, PT; Scott Oliaro, MA, ATC; Dean Crowell, MA, ATC

Sponsor: Centers for Disease Control and Prevention

You are being asked to take part in a research study. The investigators listed above are in charge of the study; other professional persons may help them or act for them.

What are some general things you should know about research studies?

Research studies are designed to gain scientific knowledge that may help other people in the future. You may not receive any direct benefit from participating. There may also be risks associated with participating in research studies.

Your participation is voluntary. You may refuse to participate, or may withdraw your consent to participate in any study at any time, and for any reason, without jeopardizing your future care and status as a student athlete at this institution or your relationship with your athletic trainer, doctor, coach or team.

As a UNC-CH 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 evaluation at UNC-CH. The researcher also may end your part in the research study. If this happens, your evaluation will not be affected. You will not be offered or receive any special consideration if you take part in this research.

Details about this particular study are discussed below. It is important that you understand this information so that you can decide in a free and informed manner whether you want to participate. You will be given a copy of this consent form. You are urged to ask the investigators 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?

Management of sport-related concussion can be challenging for clinicians, and it is important to learn more about how doctors and athletic trainers should grade the severity of concussions. The purpose of this study is to compare clinical characteristics of players who suffer a concussion to those who play football, but do not sustain concussions. The study will attempt to determine how different magnitudes of head impacts affect the risk of concussion, and to determine if certain magnitudes result in abnormal neuroimaging (MRI) and clinical characteristics (poor balance or slowed thought processes) specifically related to concussion. Additionally, comparisons will be made between concussed players with a history of previous concussion to concussed players without a history of previous concussion on measures taken from the helmet sensors (accelerometers), the imaging of your brain (MRI), clinical measures such as balance and concentration/memory tests, and duration of recovery following concussion.

How many subjects will participate in this study?

If you decide to participate, you will be one of approximately 60 subjects in this research study at any one time. Over the course of the 5 year project, there will be approximately 150 different subjects who will participate.

How long will your participation last?

Your participation in this study will initially last about 60 minutes for the pre-season baseline assessment. However, your football helmet will be fitted with a device that will measure how fast your helmet accelerates and decelerates during any impacts. These measurements will be taken during all practices and games during each of the seasons that you agree to participate. Once enrolled, you may continue to participate as long as you are a member of the UNC-CH football team, unless you decide to withdraw. There are two scenarios that might qualify you to be re-assessed on these same measures during the season: 1) if you sustain a concussion, or 2) if a teammate playing a similar position sustains a concussion, you may be asked to participate as a control subject. If asked to return for testing, you will be asked to participate in 7 additional (control subjects) or 8 additional (concussed subjects) assessments that will take approximately 45 minutes in duration. If you are recruited as control subject, you may later be enrolled as concussed subject if you sustain a concussion at some point later in the study. In this case, they would be tested again under the same protocol. These assessments will take place outside of your scheduled class time and regular football commitments. You will only be asked to participate in a baseline assessment at the time of your enrollment into the study. The information gathered at this baseline assessment will be utilized throughout the duration of the study.

What will happen if you take part in the study?

During the course of this study, the following will occur:

Pre-season screening: You will first be asked some questions about the number of concussions you have sustained over the past 5 years. You will be asked about any symptoms that you may still experience as a result of any previous concussions. You will then be tested on your ability to maintain your balance while standing on a force plate that measures how much you sway. This test will then be repeated on a firm surface (floor) and again while standing on a piece of foam. You will then be asked to take a computer test that measures your short-term memory and concentration abilities. This is a computerized neuropsychological test commonly used to assess mental processing problems after a concussion. Another brief memory test called the Standardized Assessment of Concussion will be administered at the end of the session.

Helmet fitting: Your football helmet will then be fitted with the Head Impact Telemetry System (HITS), which will measure the magnitude and location of any impacts to the helmet. The device includes 6 small (dime-sized) accelerometers that will communicate through radio frequency with a sideline computer. The 6 small accelerometers will be placed in the helmet padding, and should not cause your helmet to fit or feel any different than normal. You will be able to perform your normal football activities while wearing the device in your helmet. However, if you do feel any discomfort from the helmet, you should report immediately to one of the athletic trainers.

Post-concussion testing: In the event that you sustain a concussion during the season, you will be asked to re-take the tests outlined above under *pre-season screening.* Some of these tests will be administered twice within the first few hours of the injury (most likely at the game or practice site), while more comprehensive assessments will take place within the next 7 days following the injury. Additionally, at 2 days and 4 days post-injury, you will be asked to report to the MRI Research Center to have an image taken of your brain. Prior to the imaging, called an MRI, you will be given an intravenous (IV) injection of a contrast dye commonly used for these procedures. This dye will allow the neuroradiologist to observe the blood flowing through vessels within your brain. This MRI will take place in a large tube shaped magnet. You will be asked to lie on a long narrow table that will slide inside the magnet. The imaging and study measurements produce a knocking noise, so you will be given earplugs. You will be asked to lie still during the entire exam. The MRI will be conducted by a trained technician, and the neuroradiologist (medical doctor) assisting with our project. Although MRI may not tell us much about your concussion, the procedure will be useful in finding any more severe conditions that may have resulted as a result of your concussion. This procedure will take approximately 40 minutes. All findings from these tests will be communicated to Dr. Ciocca, the team physician.

If you are asked to participate as a control subject, you will already have undergone procedures outlined above for *pre-season screening* and *helmet fitting*. You will be asked to undergo the same procedures for *post-concussion testing* (with the exception of the second MRI), even though you will not have sustained a concussion.

Are there any reasons you should not participate?

You should not participate in this study if you have used mind altering drugs or alcohol within the last two days or if you have any associated injuries (e.g., broken bones, sprained lower extremity joints). Additionally, if you have ever been diagnosed with a stroke, have any psychiatric disorders other than depression (e.g., anxiety disorders, psychotic disorders, somatoform disorders, and substance-related disorders), or other known central nervous system diseases, you should not participate. You should also not participate if you have a condition that makes MRI unsafe for you (e.g., metal implants, cardiac pacemaker, epicardial pacemaker leads, cochlear implants, ferromagnetic aneurysm clip, or iron filings in your eyes). In the event that you should sustain a concussion and be referred for an MRI, the imaging technician will review all of the conditions with you to ensure that the MRI is safe for you to undergo.

<u>What are the possible risks or discomforts?</u>

This study might involve the following risks and/or discomforts to you:

1) The neuropsychological testing and balance testing should not be challenging during the baseline testing, or in the event that you serve as a control subject. Following concussion, these tests may be more challenging for you to complete, but will not place you in any danger or discomfort beyond that which you are experiencing from the concussion.

2) MRI is an approved imaging technique that does not involve the use of ionizing radiation (standard x-rays). It does involve the use of magnetic fields to image the body. There are no apparent risks from MRI, diffusion imaging, blood flow measurements, or oxygen tension measurements. The examination is not uncomfortable, but does take place in a small space. If you have claustrophobia (fear of enclosed spaces) you should let the technician in charge of the examination know. In addition, there may be uncommon or previously unrecognized risks that might occur.

3) There is a slight risk of contrast reaction to the intravenous contrast dye (gadolinium DTPA) given for the MRI. This risk is estimated to be less than 1:100,000 chance of a serious reaction. Becasuse of this slight risk, the contrast is administered only when a physician is present, and a contrast allergy treatment kit is available in the imaging suite.

<u>What are the possible benefits?</u>

Standard care for a UNC-CH football player following a concussion is to undergo a physician examination and most of the clinical assessments utilized in this study (neuropsychological testing, postural stability testing, and symptom checklist). The direct benefit for participating is that in the event of a concussive injury, you will receive more extensive follow-up assessments (including neuroimaging – MRI), regardless of the severity of the concussion. Your participation in this study will potentially provide you and the medical team with additional information about your injury that could be helpful in making return to play decisions. For example, in the rare event that the MRI revealed damage to one of your blood vessels, you would be informed by the neuroradiologist that follow-up treatment is recommended. Wearing the HITS system in your helmet will also provide the athletic trainers with additional information about the helmet impacts you receive.   Your participation may benefit society if the results of this study find new technologies that can be useful in helping clinicians make safe return to play decisions.

<u>What if we learn about new risks 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?
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-CH will take all steps allowable by law to protect the privacy of personal information.

Your data will be coded with a number and stored in a computer. No individual will have access to the computer or the number that identifies your data. Access to this information is limited to Dr. Kevin Guskiewicz, the principal investigator, and Dr. Mario Ciocca, the team physician.

Will you be paid for participating?
You will not be paid for your participation in this study.

Will it cost you anything to participate?
There will be no costs to you for participating.

Who is sponsoring this study?
This research is being funded by the Centers for Disease Control and Prevention.

What will happen if you are injured by this research?
All types of research involve possible risk, some including the risk of personal injury. In spite of all precautions, you might develop complications from participating in this study. If such complications arise, the researchers will assist you in obtaining appropriate medical treatment, but any costs associated with the treatment will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to compensate you for any such complications or injuries, or for related medical care. However, by signing this form, you do not waive 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 jeopardizing your future care and status as a student athlete at UNC-CH or your relationship with your athletic trainer, doctor, coach or team.. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped.

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 further questions, or if a research-related injury occurs, you should call Dr. Kevin Guskiewicz at (919)962-5175 or Dr. Mario Ciocca at (919) 966-3655.

What if you have questions about your rights as a subject?

This research has been reviewed and approved by the Committee on the Protection of the Rights of Human Subjects (Medical IRB) at the University of North Carolina at Chapel Hill. If you have any questions or concerns regarding your rights as a research subject, you may contact the Chairman of the Committee at (919) 966-1344.

- -

Subject's Agreement:

I have read the information provided above. I voluntarily agree to participate in this study.

____ __________________

Signature of Research Subject Date

____

Printed Name of Research Subject

____ __________________

Signature of Person Obtaining Consent Date

____

Printed Name of Person Obtaining Consent

APPENDIX B

Tables

Table 1. Demographic Information

ht	wt	age
76	285.6	20
77	278.2	23
68	181.2	21
74	217	19
71	252	20
73	255	21
71	210.4	21
75	240	20
78	290	23
69.2	202.4	19
75	273.8	19
74	300	21
75	252	21
76	276.2	20
76	295.6	22
74.6	206.8	22
73	256.4	20
77.4	300.2	18
74	268.2	23
74	233	20
70.6	218	21
73	200	23
72	255	19
69	180	21
75	317.2	21
76.6	242	19
71	236.8	19
78	295	24
73	216.8	20
71	270	23
74	300	19
74	241.2	19
70	198.2	24
73.6	213.8	20
75.6	326	19
76	231.6	19
71	206	27
71	184	22
71	219	19
72	187	20
72	167	21
74	220	19
72	235	21
3156.6	10433.6	892
73.41	242.64	20.74

Table 2. Means (±SD) compared between pre-season baseline and high impact testing condition (n=24)

Outcome Measure	Baseline	High-Impact	F	p-value	Effect Size
Simple reaction time-1	237.34 ± 35.93	248.38 ± 29.89	0.492	0.491	0.31
Simple reaction time-2	229.67±47.04	228.85±51.40	0.068	0.796	0.017
Math processing*	20.58±5.99	23.56±7.24	17.04	0.001*	0.5
Matching to sample	40.3135±13.99	43.56±14.49	0.498	0.488	0.23
Sleep Scale*	3.0417±1.55	3.79±1.69	6.52	0.019*	0.48
Procedural Reaction Time	84.85±17.66	99.77±28.35	1.43	0.245	0.84
Code Sub 9	51.91±11.21	53.40±7.77	0.027	0.87	0.13
Memory Search 6	81.11±13.60	85.02±17.83	0.087	0.771	0.29
Total # of symptoms reported	1.65±2.06	3.04±2.76	3.54	0.075	0.67
Total symptom score	4.04±5.96	5.22±5.89	0.209	0.652	0.2
Somatosensory	96.69±2.62	98.18±4.26	0.065	0.801	0.57
Visual	92.10±5.65	90.08±11.19	0.101	0.754	0.36
Vestibular	78.07±10.89	77.99±11.02	0.126	0.727	0.007
Composite	81.34±5.65	80.10±7.66	0.015	0.905	0.22

* Indicates significance at the .05 level

Table 3. Means (±SD) compared between pre-season baseline and low impact testing condition (n=36)

Outcome Measure	Baseline	Low-Impact	F	p-value	Effect Size
Simple Reaction Time 1*	238.89±33.57	252.92±28.27	6.012	0.020*	0.42
Simple Reaction Time 2	233.35±42.34	237.01±33.72	0.943	0.338	0.45
Math Processing*	20.45±6.11	22.63±6.61	10.584	0.003*	0.36
Match To Sample	40.49±13.39	47.85±13.21	2.129	0.154	0.55
Sleep Scale	2.97±1.66	3.06±1.41	3.77	0.061	0.05
Procedural Reaction Time	88.50±17.58	97.27±23.16	0.758	0.390	0.5
Code Sub 9*	51.65±11.40	55.38±9.59	4.836	0.035*	0.33
Memory Search 6*	79.10±16.95	89.72±19.11	5.402	0.026*	0.63
Total # symptoms reported	1.81±2.44	2.61±2.567	1.4	0.245	0.33
Total symptom score	3.92±6.583	4.03±4.582	0.001	0.977	0.02
Somatosensory	97.09±2.83	96.03±3.50	1	0.325	0.37
Visual	92.02±6.19	90.05±10.88	4.052	0.052	0.32
Vestibular*	76.92±11.52	79.80±8.82	8.677	0.006*	0.25
Composite*	81.21±5.45	81.76±7.22	12.754	0.001*	0.1

* Indicates significance at the .05 level.

APPENDIX C

Figures

Figure 1.   Accelerometers that fit into the Riddell Helmets.

Figure 2. Sideline control unit that stores and displays the information collected.

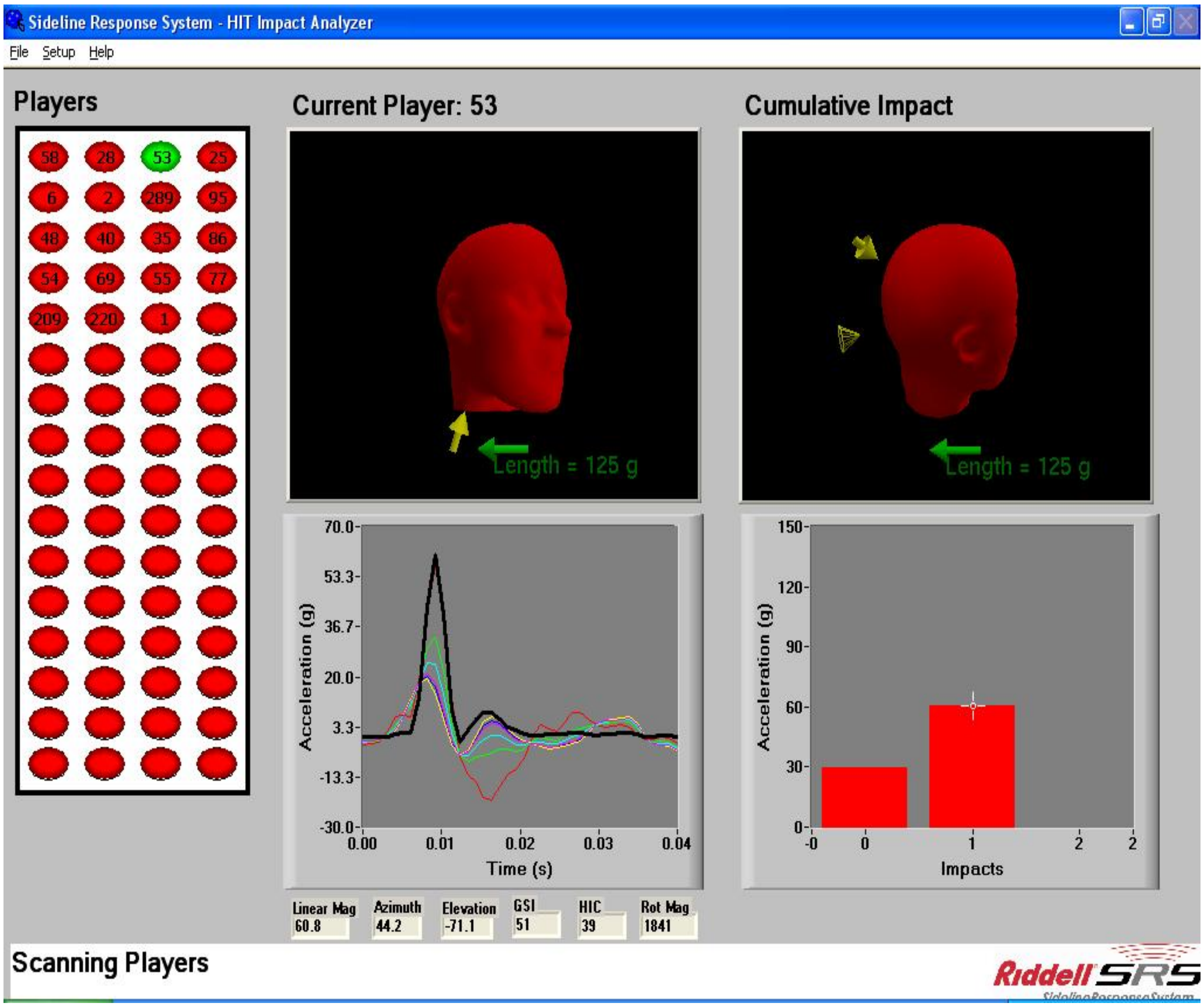


Figure 3. Display screen that shows the players' impact history and information.

Figure 4. NeuroCom used for the SOT test which assesses balance performance.

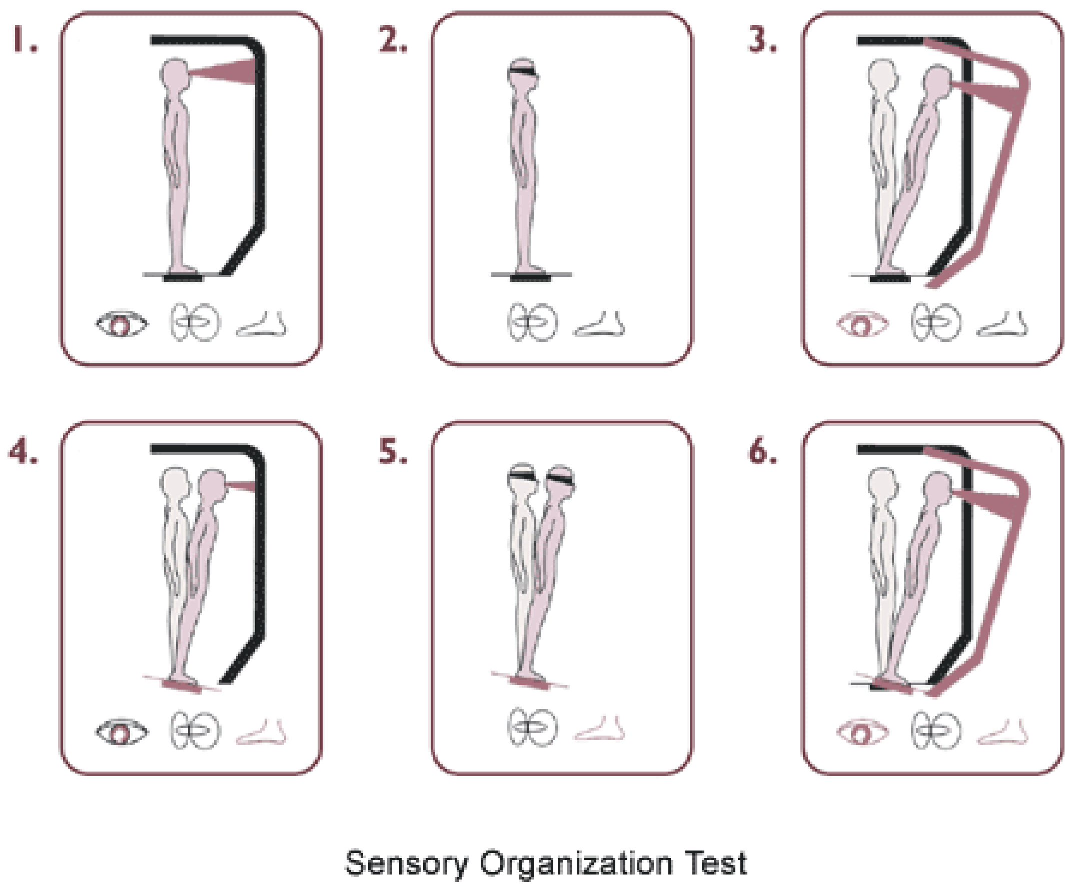


Figure 5. Various SOT conditions that the subject is tested on.

Graded Symptom Checklist (GSC)

SYMPTOM	NONE	MILD		MODERATE		SEVERE	
	0	1	2	3	4	5	6
Headache							
Nausea							
Vomiting							
Balance Problems							
Dizziness							
Sensitivity to Light							
Blurred Vision							
Sensitivity to Noise							
Nervousness							
Numbness/ Tingling							
Feeling Slowed Down							
Feeling like “In a Fog”							
Difficulty Concentrating							
Difficulty Remembering							
Neck Pain							
Fatigue							
Drowsiness							
Difficulty sleeping							
Sadness							
Irritability							

Figure 6. Graded symptom checklist; a 7 pt. likert scale.

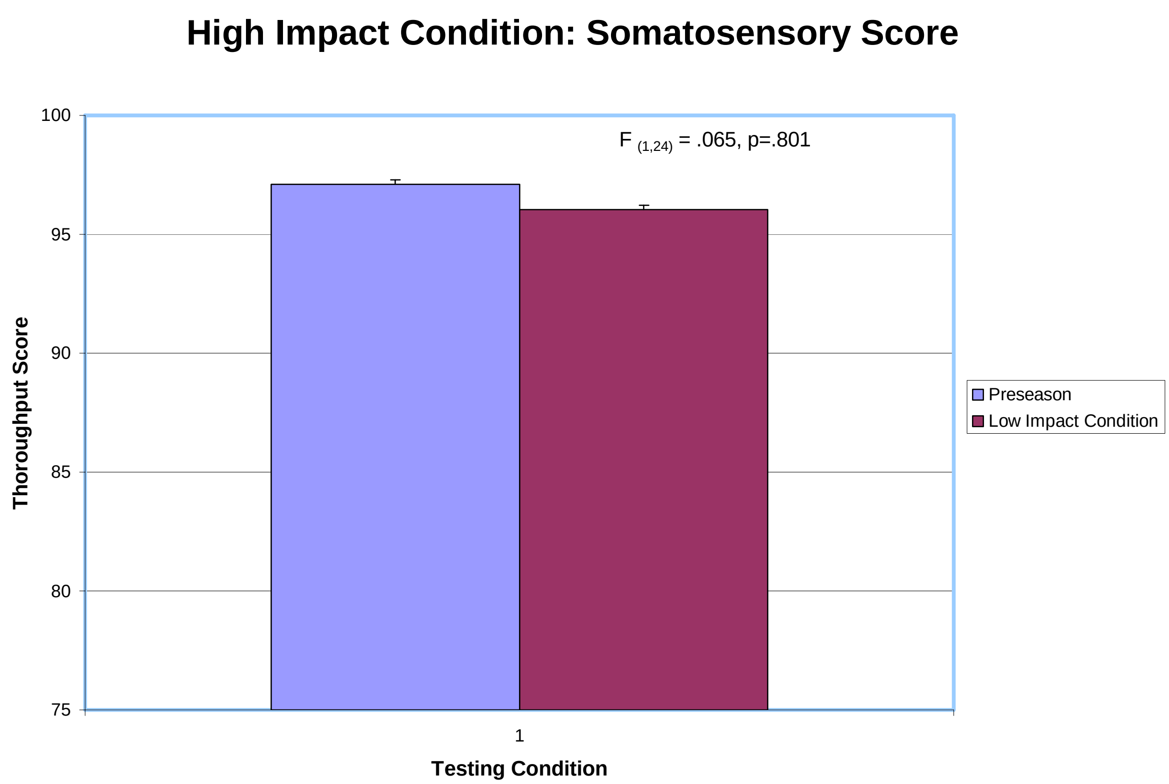

High Impact Condition: Somatosensory Score
F (1,24) = .065, p=.801
100
95
90
85
80
75
Thoroughput Score
1
Testing Condition
Preseason
Low Impact Condition

Figure 7

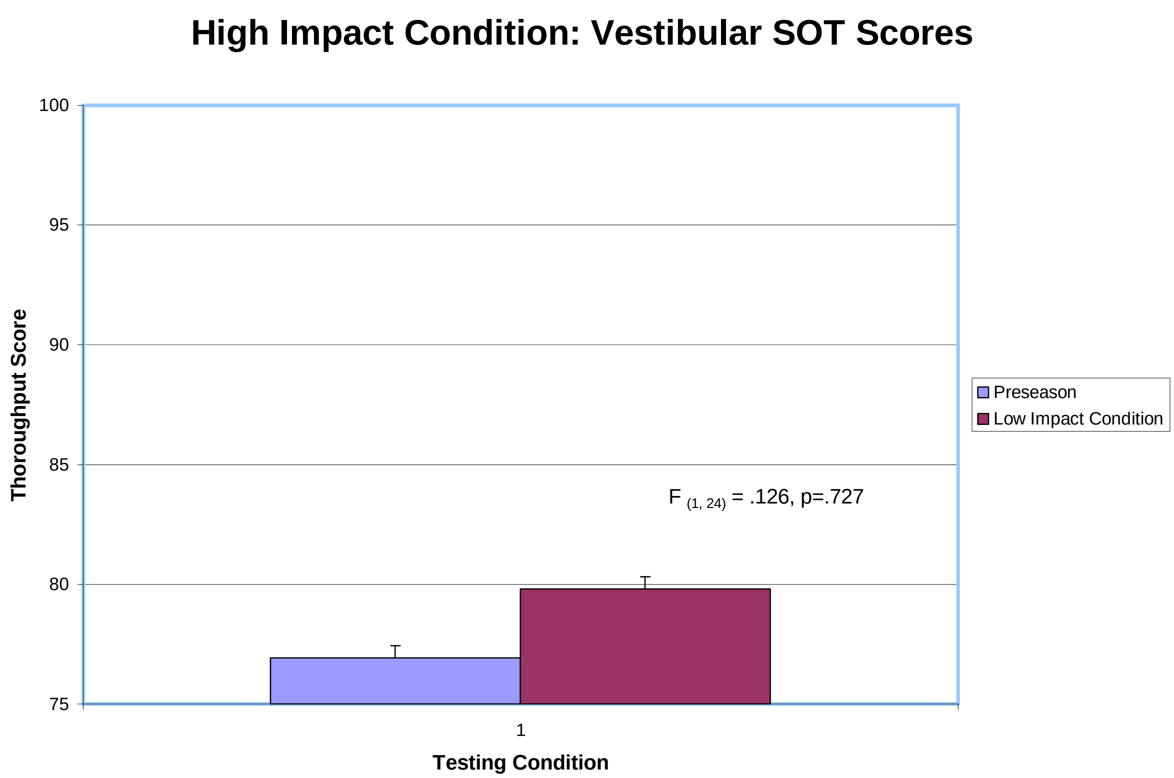

High Impact Condition: Vestibular SOT Scores
100
95
90
85
80
75
Thoroughput Score
F (1, 24) = .126, p=.727
Preseason
Low Impact Condition
1
Testing Condition

Figure 8

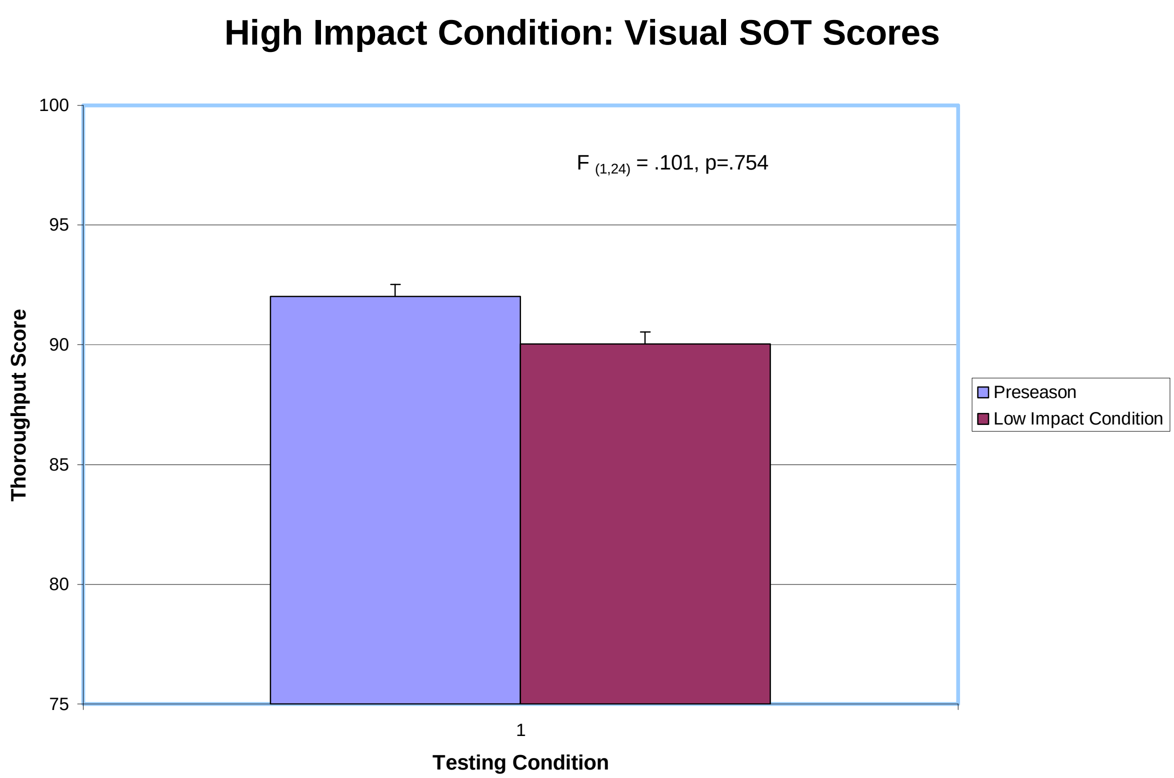

High Impact Condition: Visual SOT Scores
F (1,24) = .101, p=.754
100
95
90
85
80
75
Thoroughput Score
1
Testing Condition
Preseason
Low Impact Condition

Figure 9

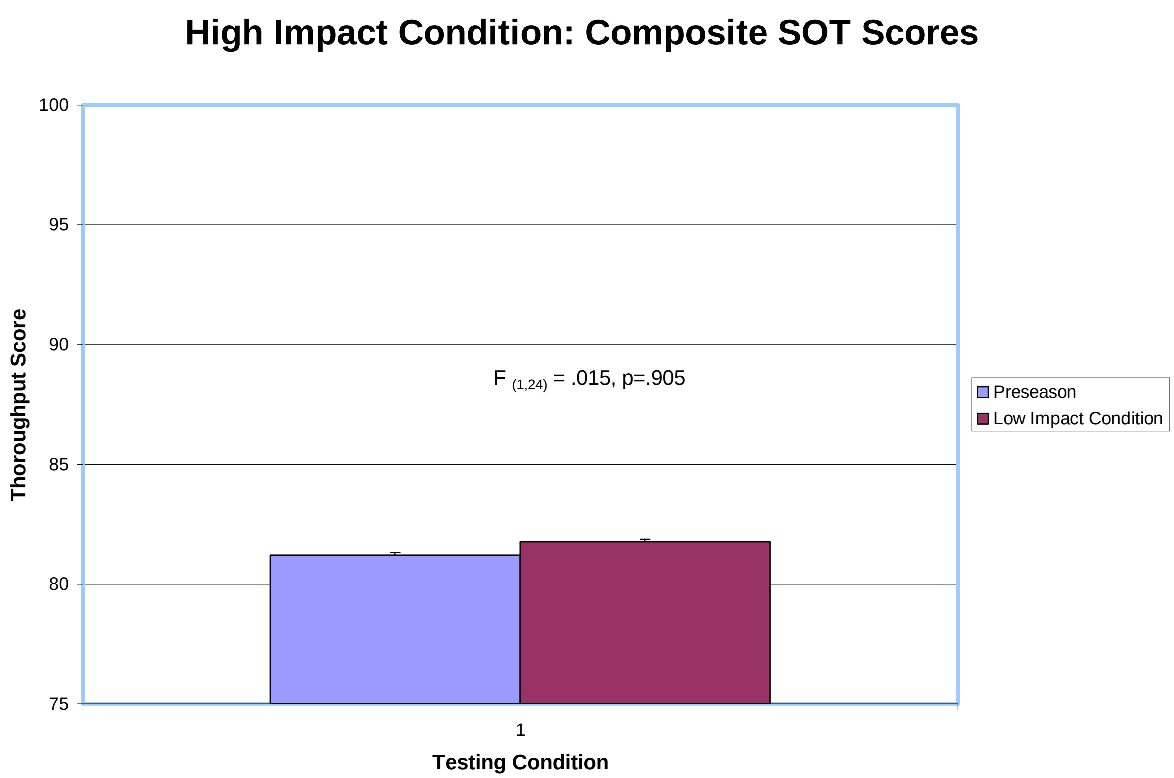

High Impact Condition: Composite SOT Scores
100
95
90
85
80
75
Thoroughput Score
F (1,24) = .015, p=.905
Preseason
Low Impact Condition
1
Testing Condition

Figure 10

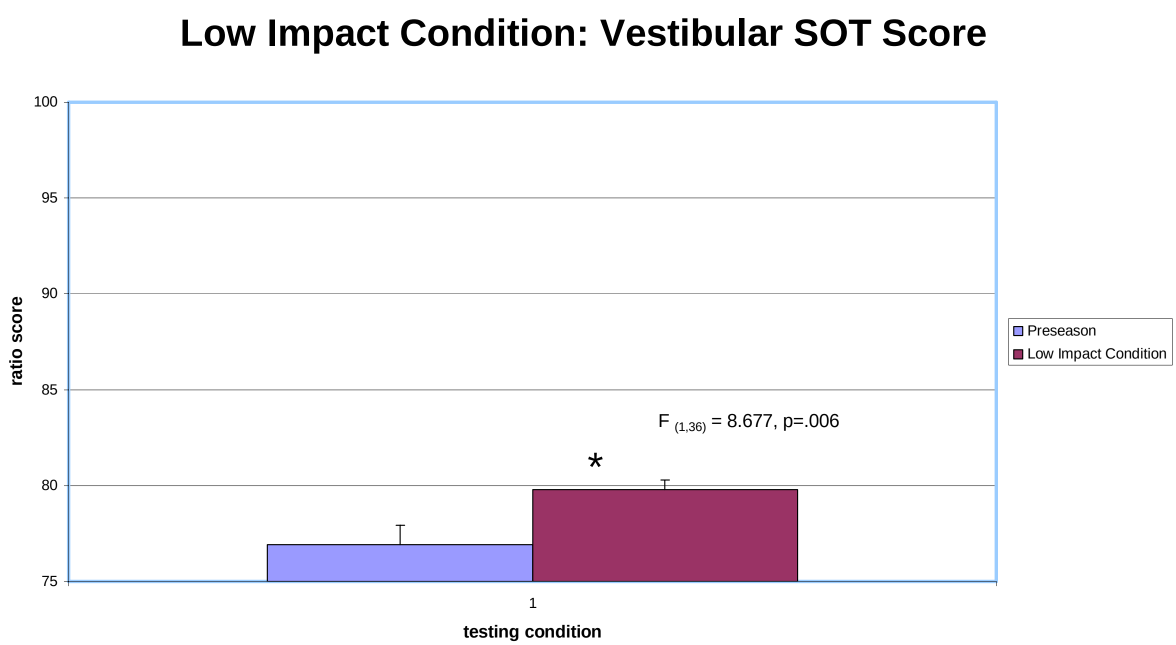

Low Impact Condition: Vestibular SOT Score
100
95
90
85
80
75
ratio score
F (1,36) = 8.677, p=.006
*
1
testing condition
Preseason
Low Impact Condition

Figure 11

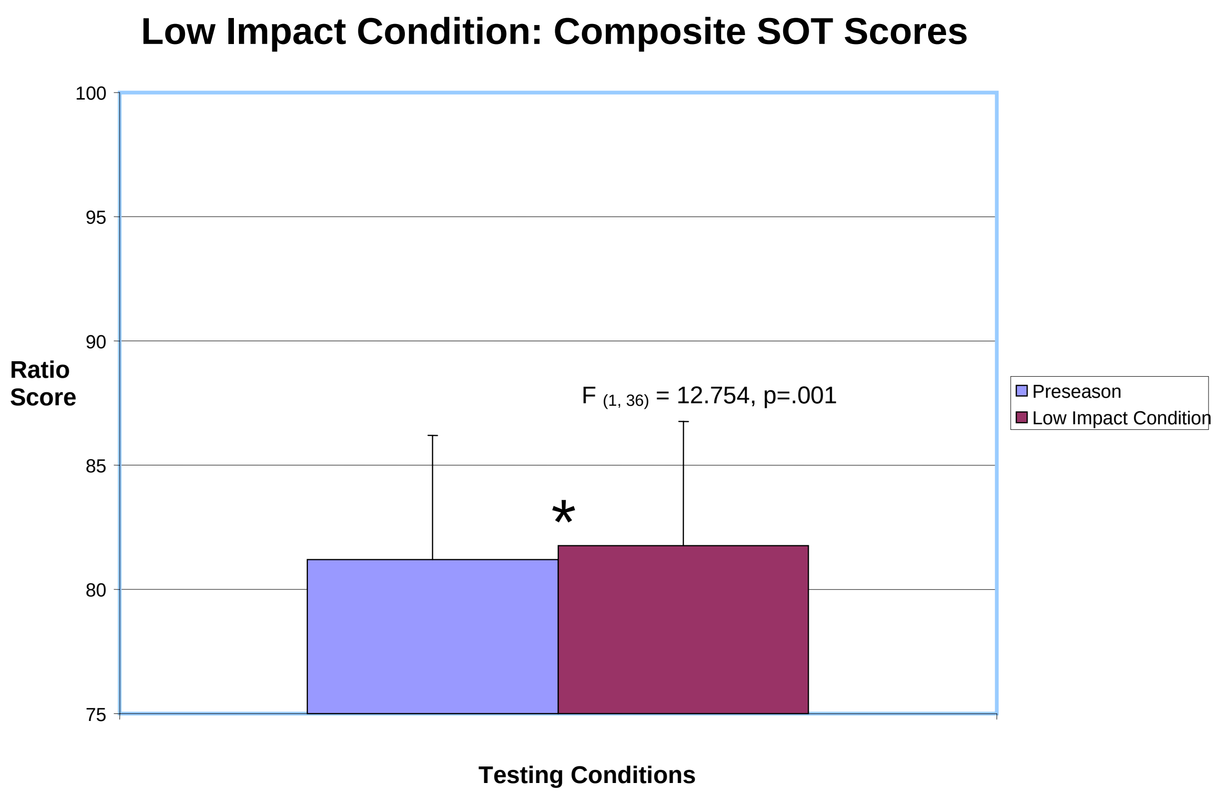

Low Impact Condition: Composite SOT Scores
100
95
90
85
80
75
Ratio Score
F (1, 36) = 12.754, p=.001
*
Preseason
Low Impact Condition
Testing Conditions

Figure 12

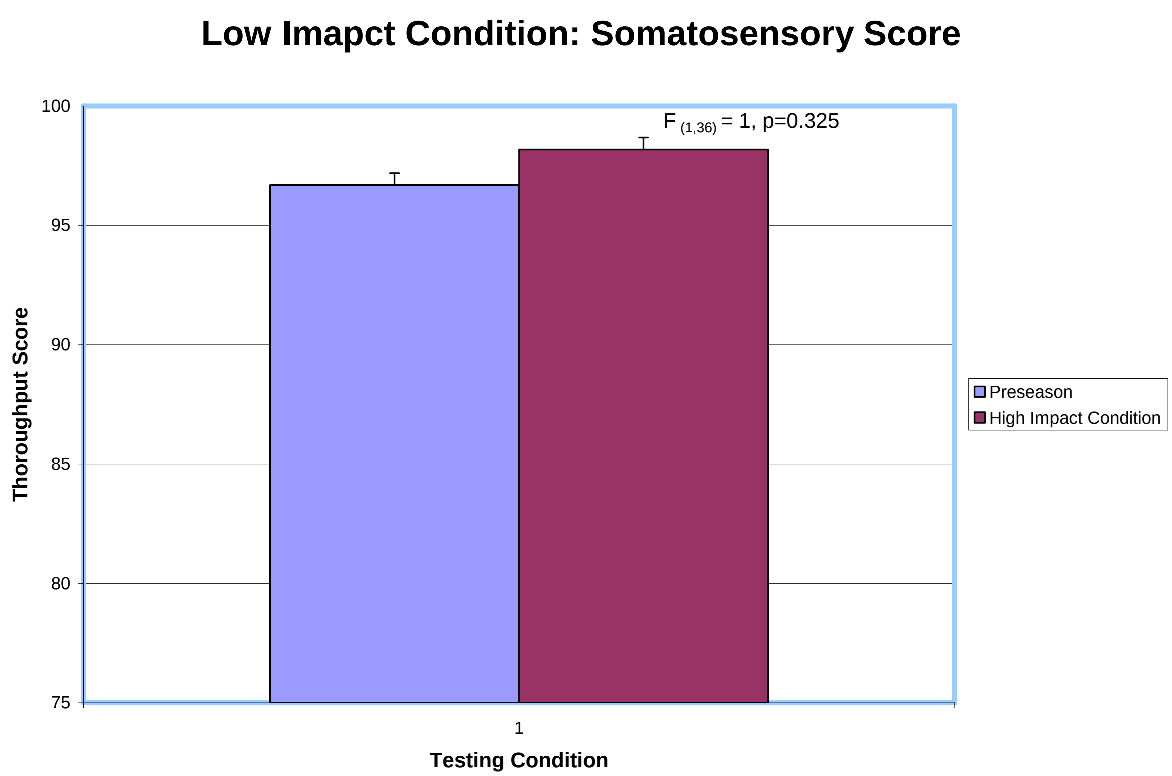

Low Imapct Condition: Somatosensory Score
F (1,36) = 1, p=0.325
100
95
90
85
80
75
Thoroughput Score
1
Testing Condition
Preseason
High Impact Condition

Figure 13

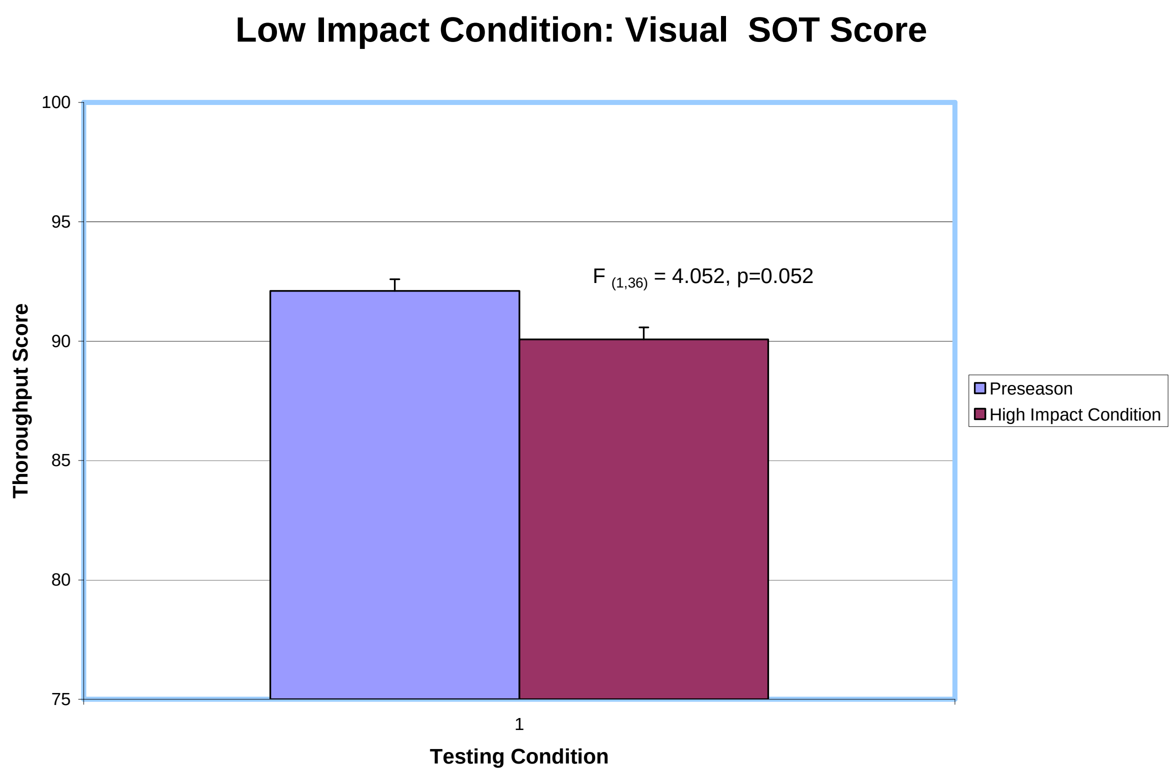

Low Impact Condition: Visual SOT Score
100
95
90
85
80
75
Thoroughput Score
F (1,36) = 4.052, p=0.052
Preseason
High Impact Condition
1
Testing Condition

Figure 14

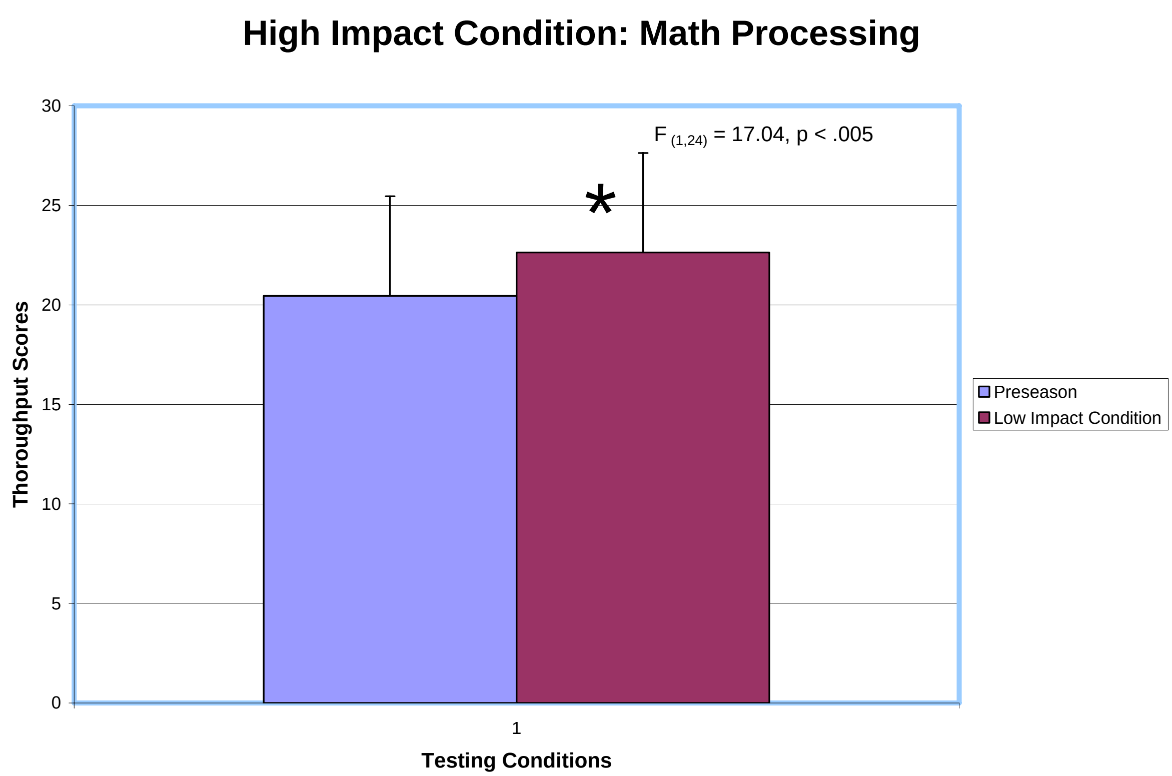

High Impact Condition: Math Processing
F (1,24) = 17.04, p < .005
*
Thoroughput Scores
30
25
20
15
10
5
0
1
Testing Conditions
Preseason
Low Impact Condition

Figure 15

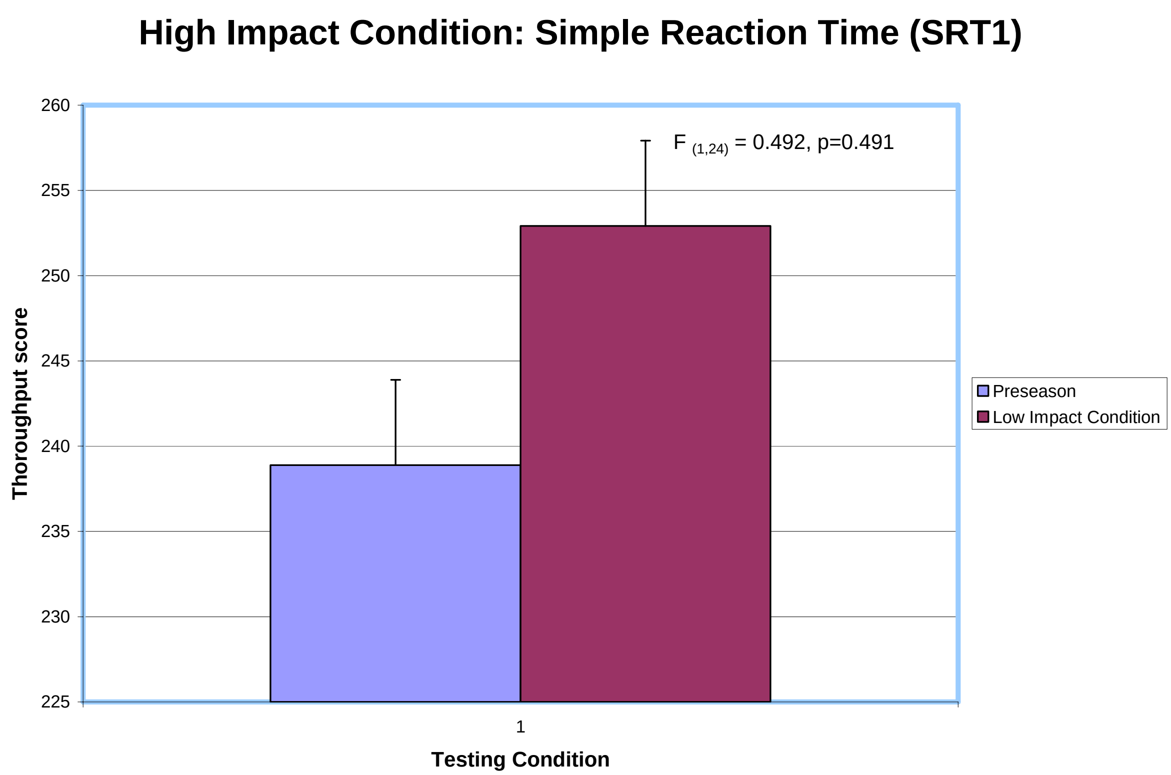

High Impact Condition: Simple Reaction Time (SRT1)
F (1,24) = 0.492, p=0.491
260
255
250
245
240
235
230
225
Thoroughput score
1
Testing Condition
Preseason
Low Impact Condition

Figure 16

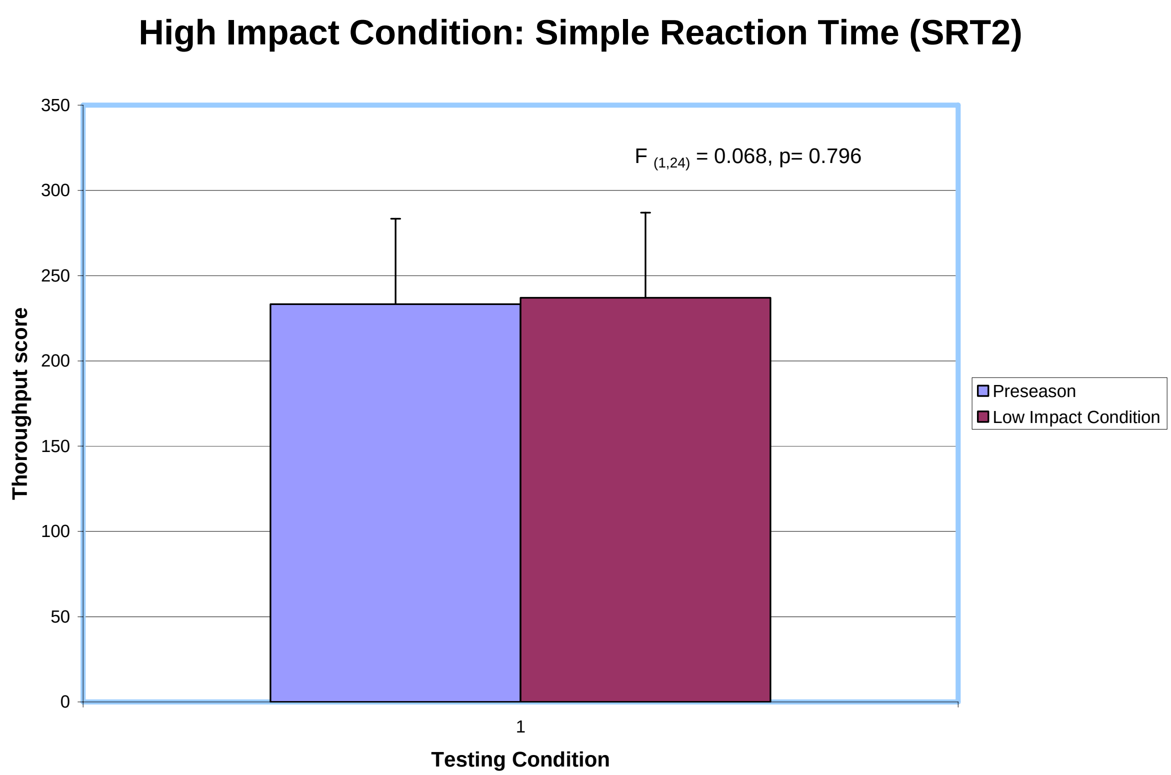

High Impact Condition: Simple Reaction Time (SRT2)
F (1,24) = 0.068, p= 0.796
350
300
250
200
150
100
50
0
Thoroughput score
1
Testing Condition
Preseason
Low Impact Condition

Figure 17

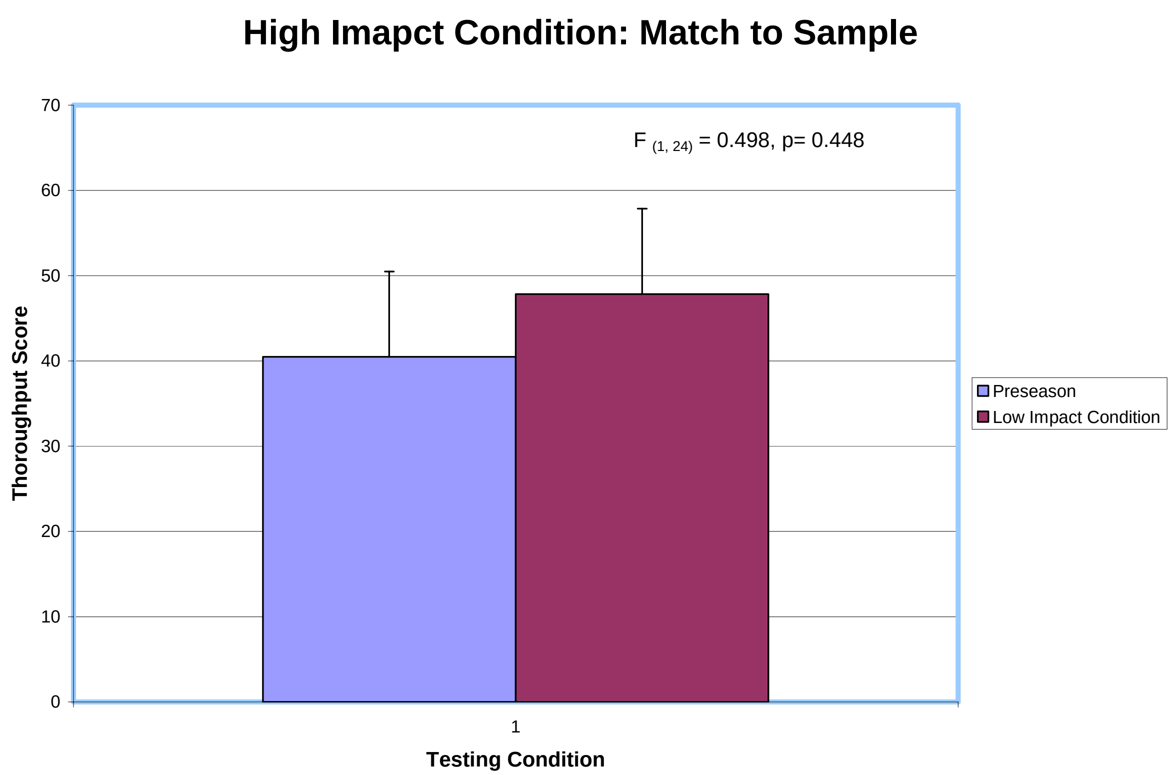
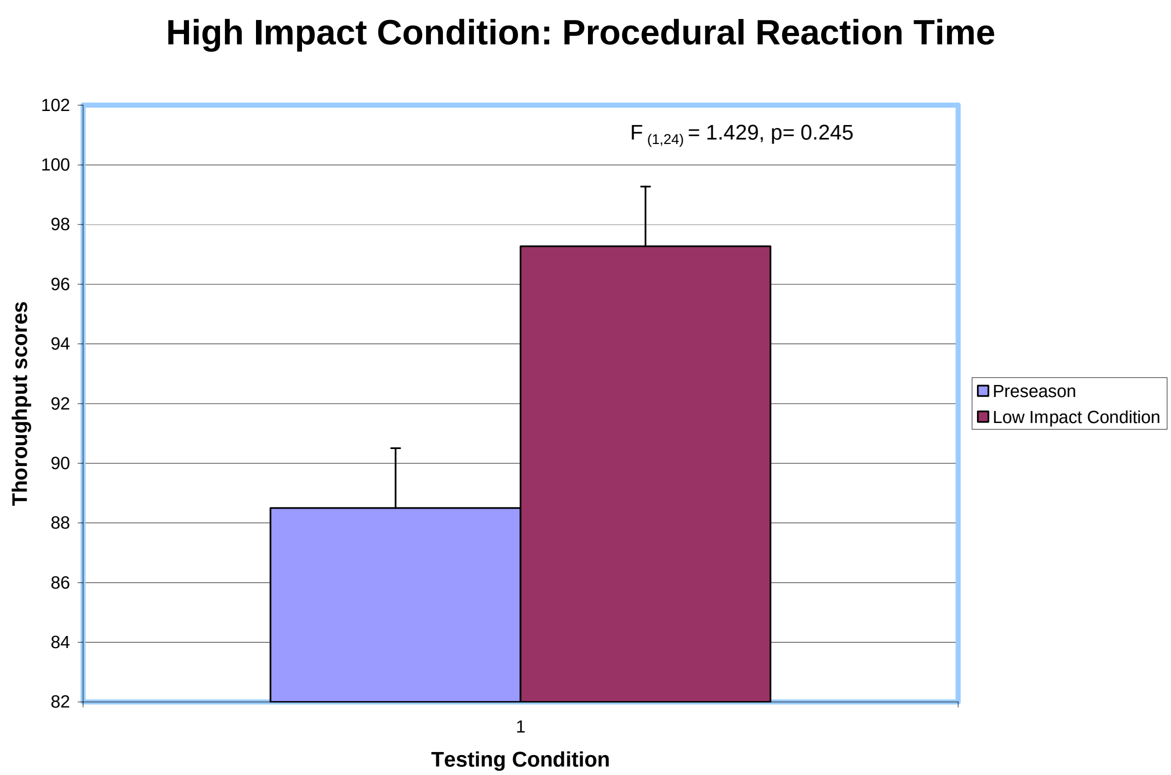
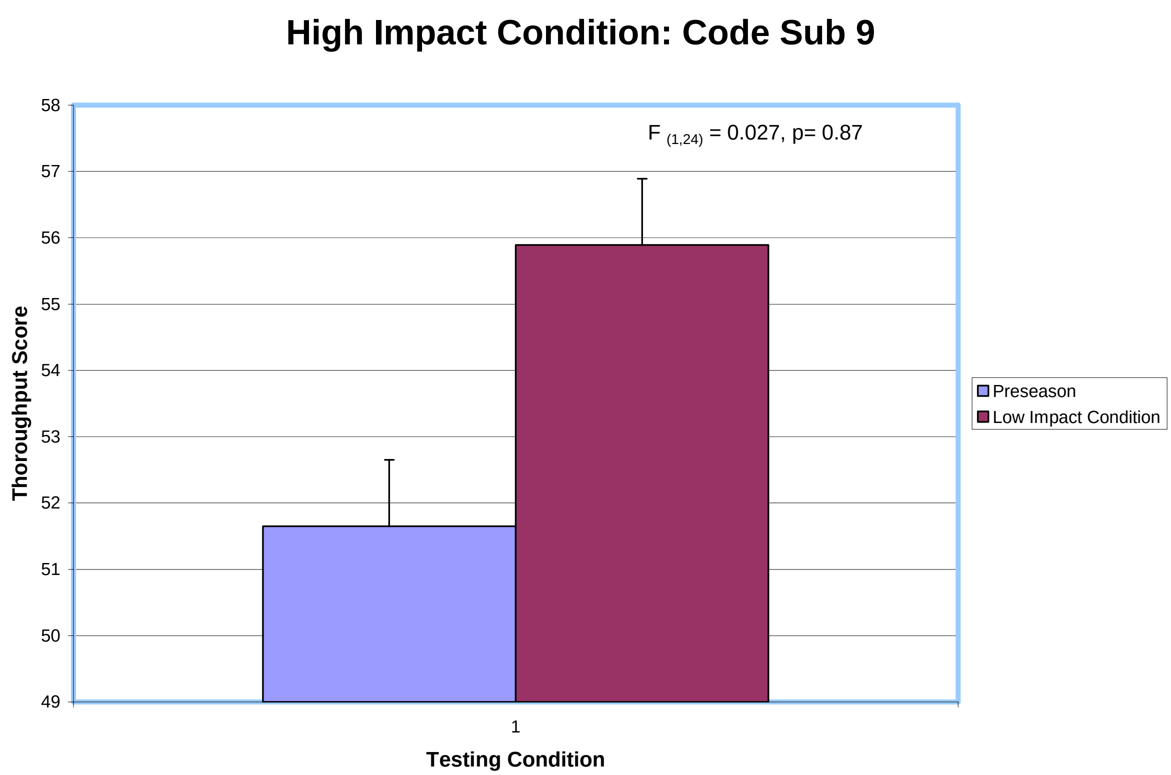

High Imapct Condition: Match to Sample
F (1, 24) = 0.498, p= 0.448
Thoroughput Score
70
60
50
40
30
20
10
0
1
Testing Condition
Preseason
Low Impact Condition

Figure 18



High Impact Condition: Procedural Reaction Time
F (1,24) = 1.429, p= 0.245
102
100
98
96
94
92
90
88
86
84
82
Thoroughput scores
1
Testing Condition
Preseason
Low Impact Condition

Figure 19



High Impact Condition: Code Sub 9
F (1,24) = 0.027, p= 0.87
58
57
56
55
54
53
52
51
50
49
Thoroughput Score
1
Testing Condition
Preseason
Low Impact Condition

Figure 20

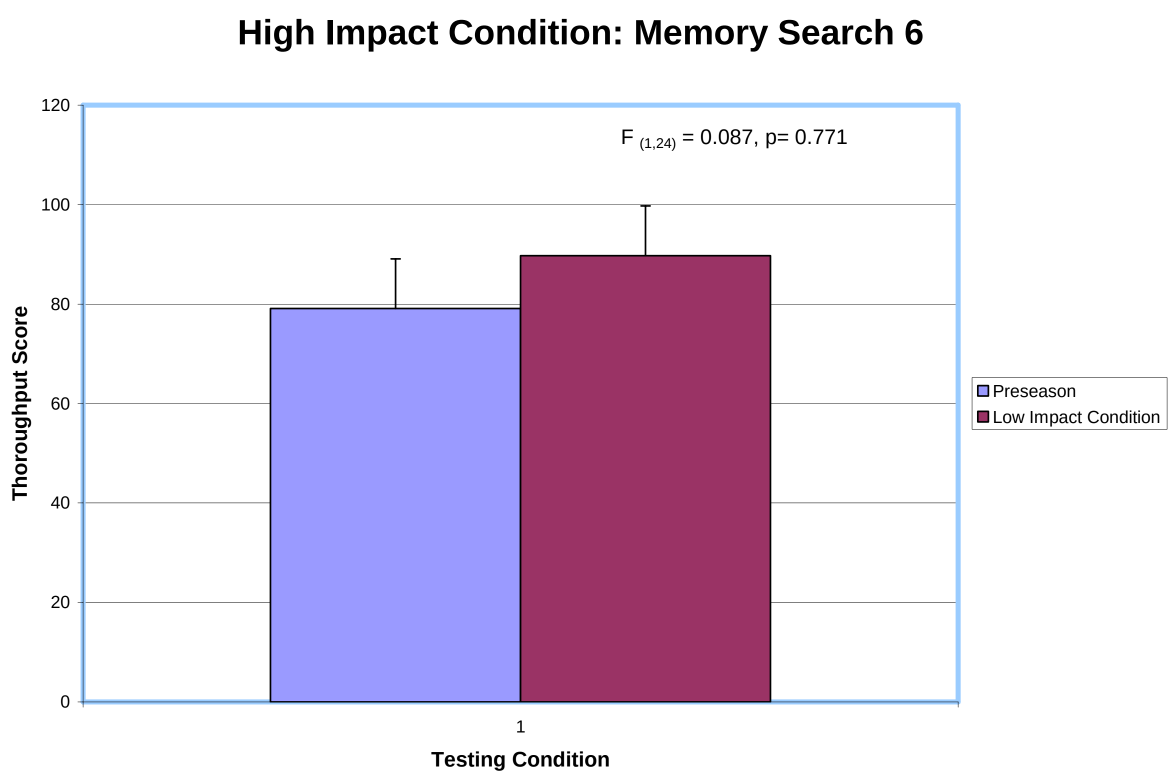

High Impact Condition: Memory Search 6
F (1,24) = 0.087, p= 0.771
120
100
80
60
40
20
0
Thoroughput Score
1
Testing Condition
Preseason
Low Impact Condition

Figure 21

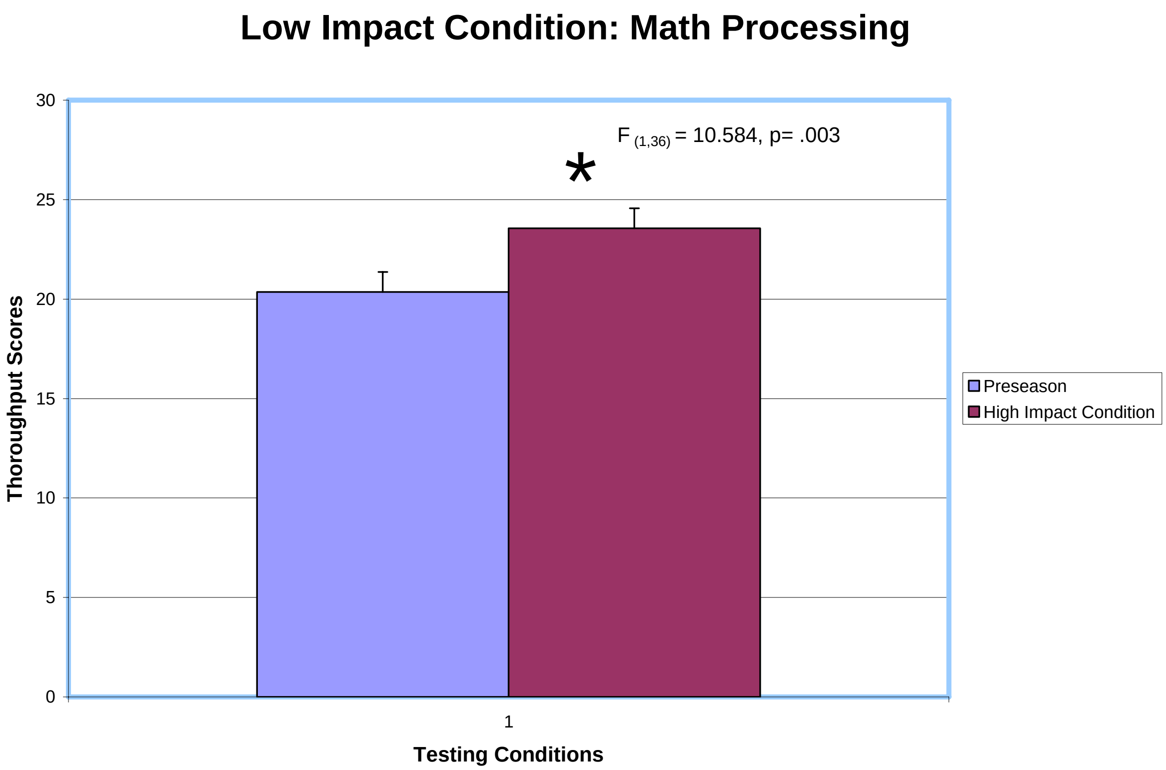

Low Impact Condition: Math Processing
F (1,36) = 10.584, p= .003
*
30
25
20
15
10
5
0
Thoroughput Scores
1
Testing Conditions
Preseason
High Impact Condition

Figure 22

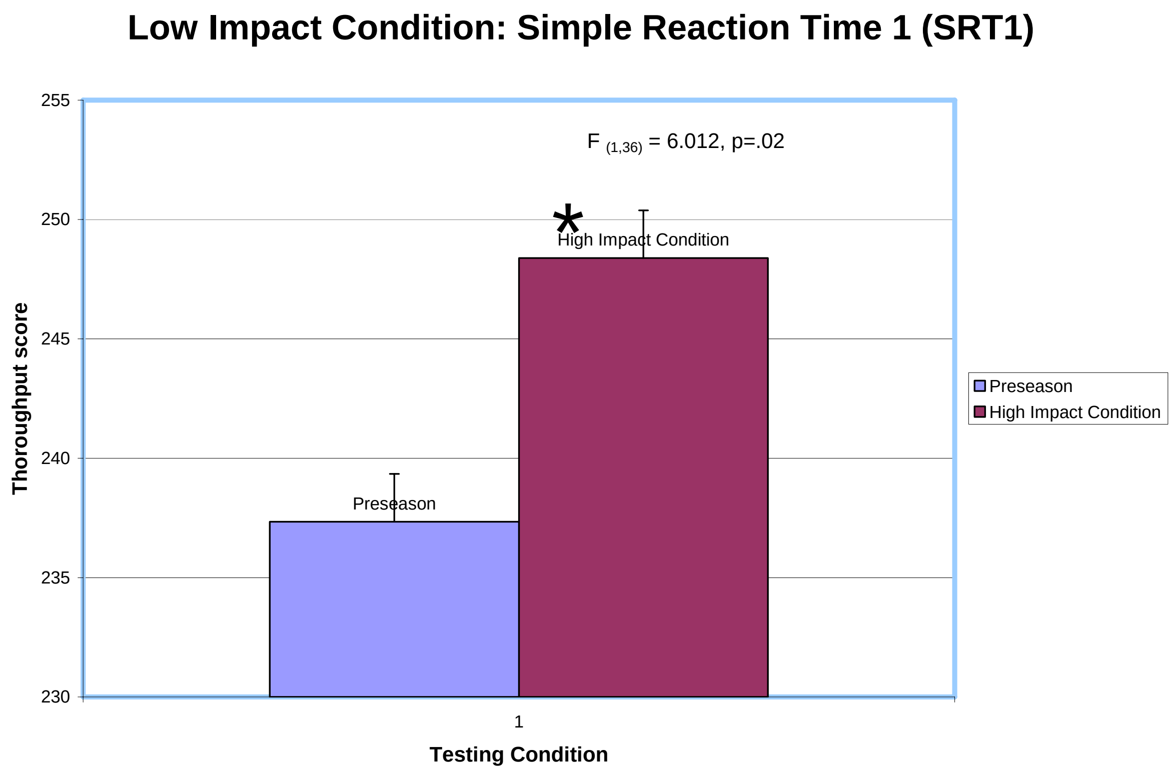
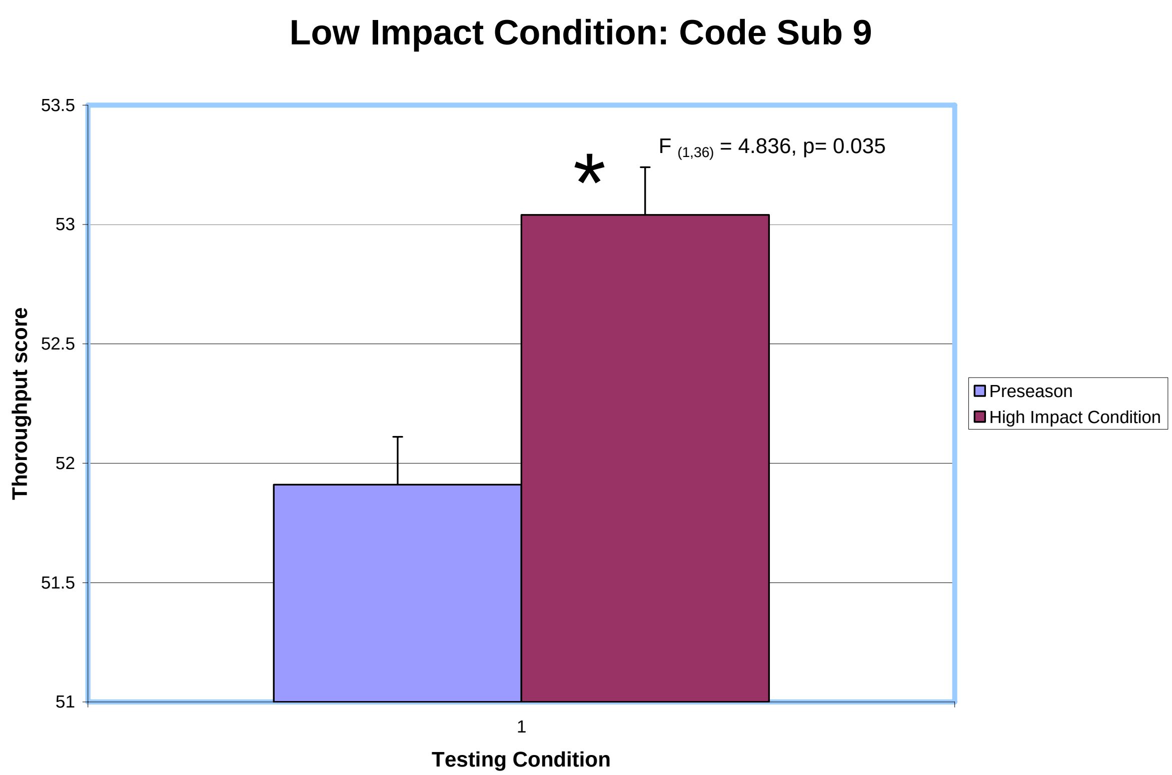
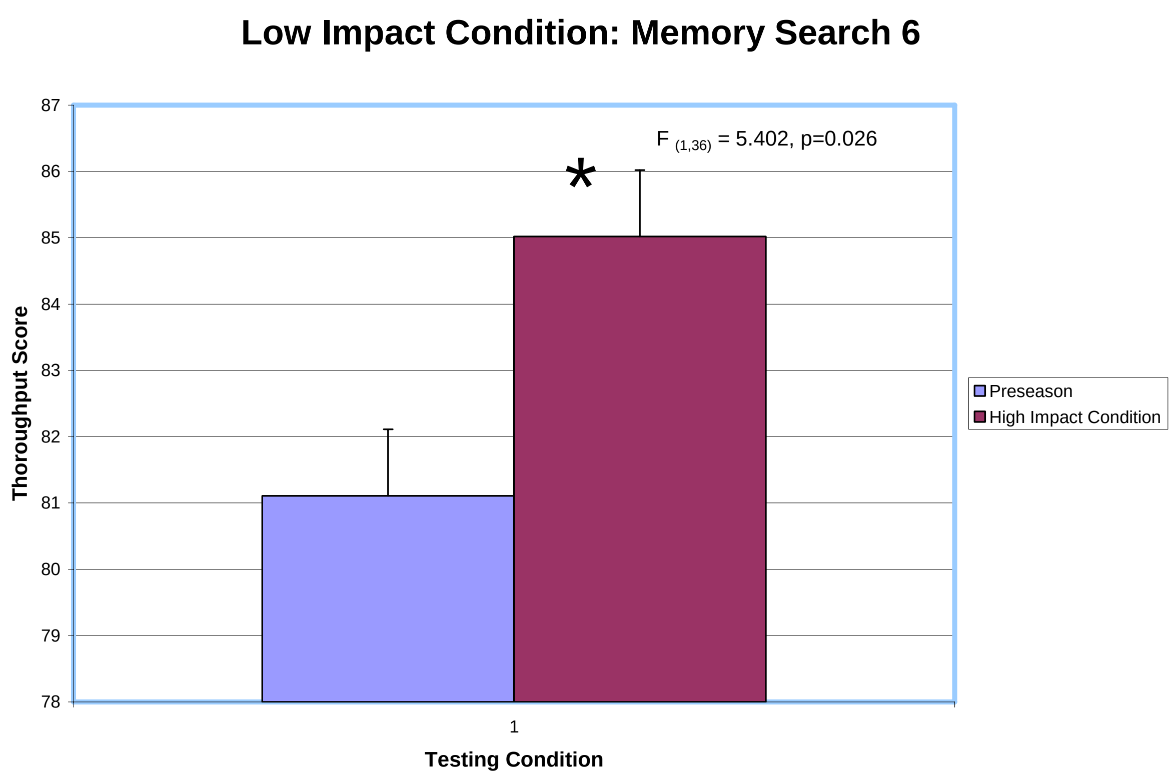

Low Impact Condition: Simple Reaction Time 1 (SRT1)
255
250
245
240
235
230
F (1,36) = 6.012, p=.02
*
High Impact Condition
Preseason
Thoroughput score
1
Testing Condition
Preseason
High Impact Condition

Figure 23



Low Impact Condition: Code Sub 9
53.5
53
52.5
52
51.5
51
Thoroughput score
*
F (1,36) = 4.836, p= 0.035
1
Testing Condition
Preseason
High Impact Condition

Figure 24



Low Impact Condition: Memory Search 6
F (1,36) = 5.402, p=0.026
*
87
86
85
84
83
82
81
80
79
78
Thoroughput Score
1
Testing Condition
Preseason
High Impact Condition

Figure 25

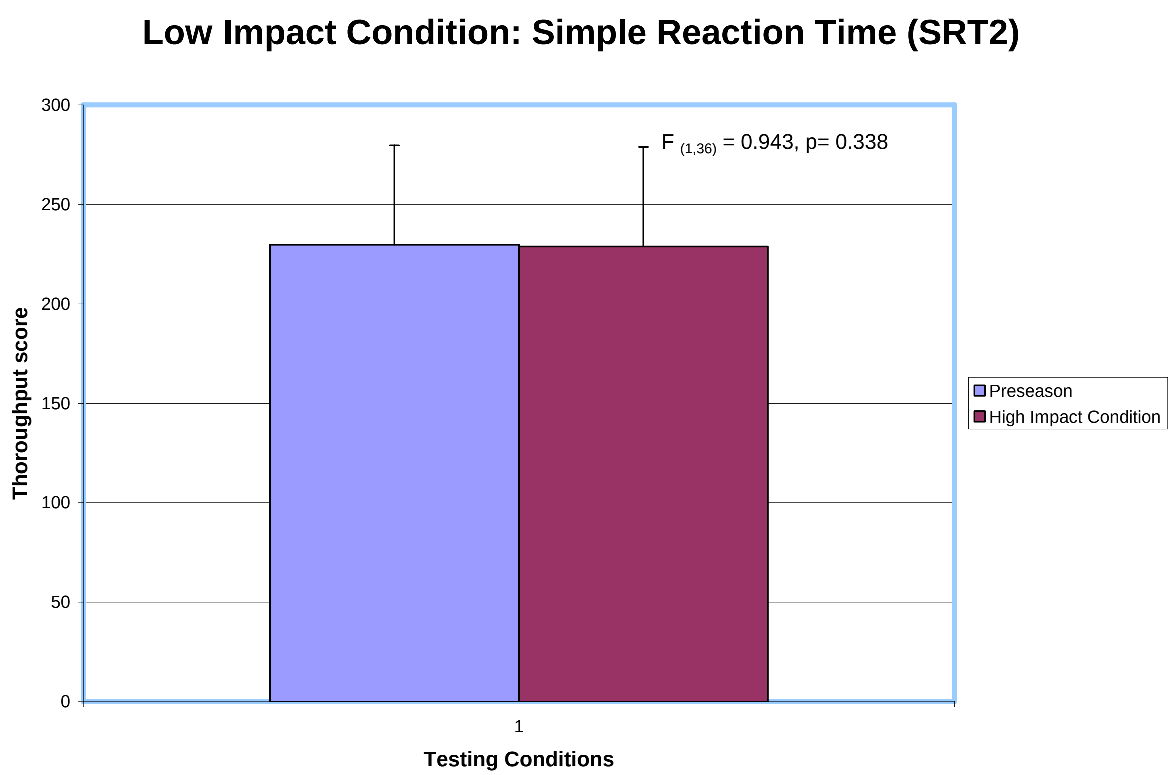

Low Impact Condition: Simple Reaction Time (SRT2)
F (1,36) = 0.943, p= 0.338
300
250
200
150
100
50
0
Thoroughput score
1
Testing Conditions
Preseason
High Impact Condition

Figure 26

Low Impact Condition: Match to Sample

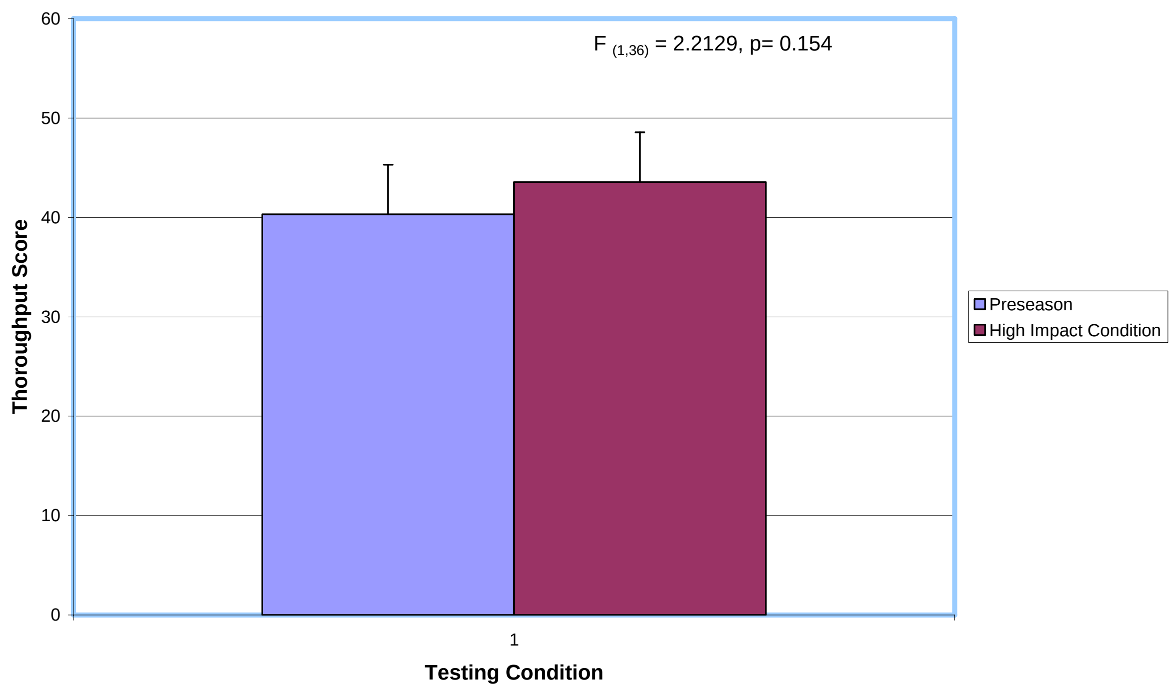


Figure 27

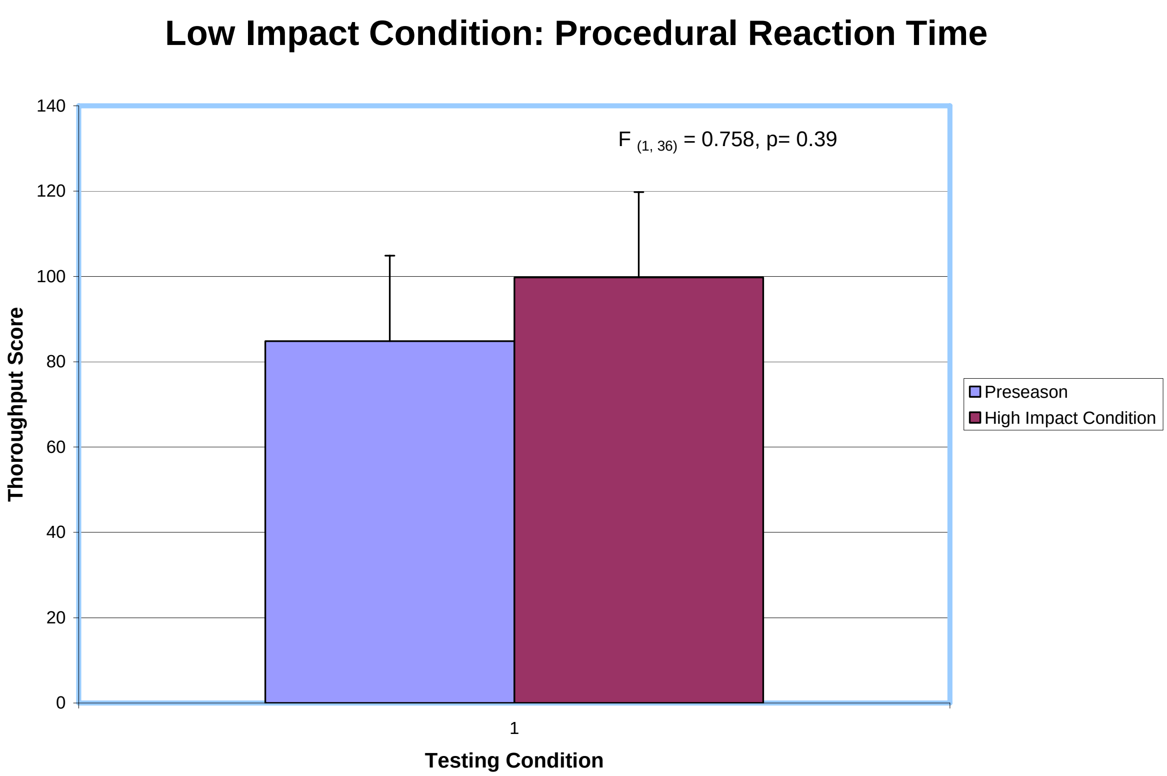

Low Impact Condition: Procedural Reaction Time
F (1, 36) = 0.758, p= 0.39
140
120
100
80
60
40
20
0
Thoroughput Score
1
Testing Condition
Preseason
High Impact Condition

Figure 28

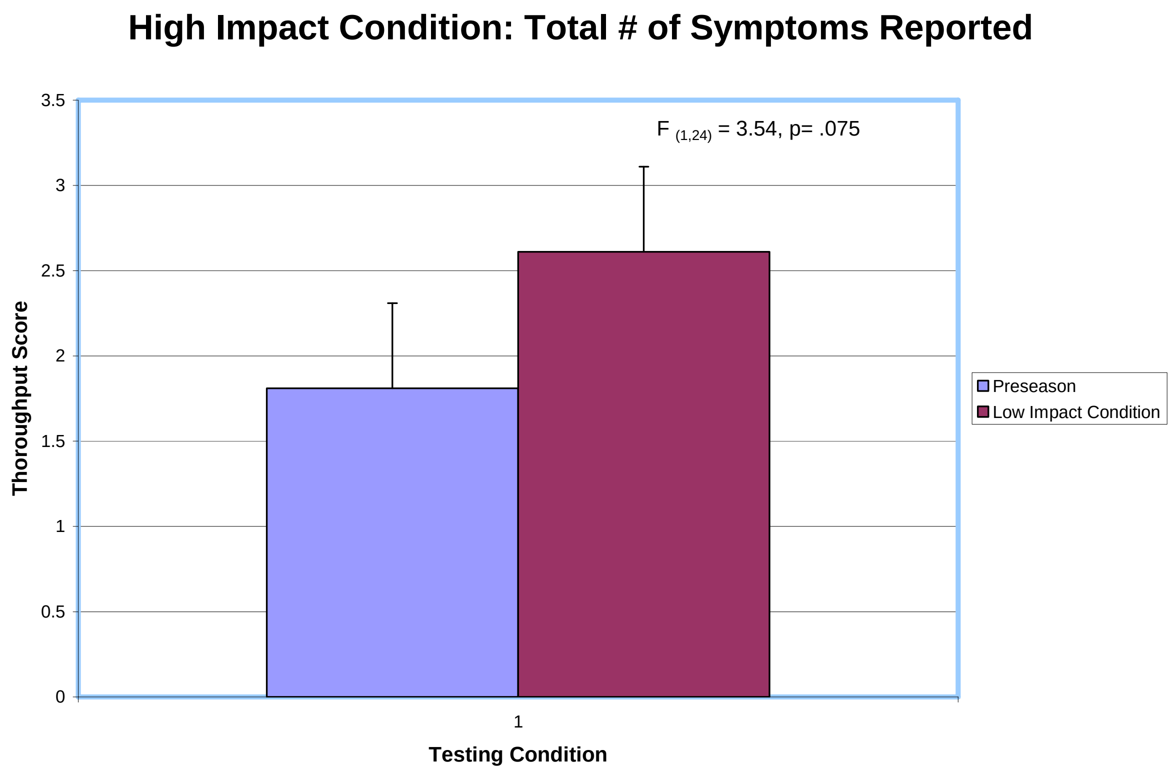

High Impact Condition: Total # of Symptoms Reported
$F_{(1,24)}$ = 3.54, p= .075
Thoroughput Score
3.5
3
2.5
2
1.5
1
0.5
0
1
Testing Condition
Preseason
Low Impact Condition

Figure 29

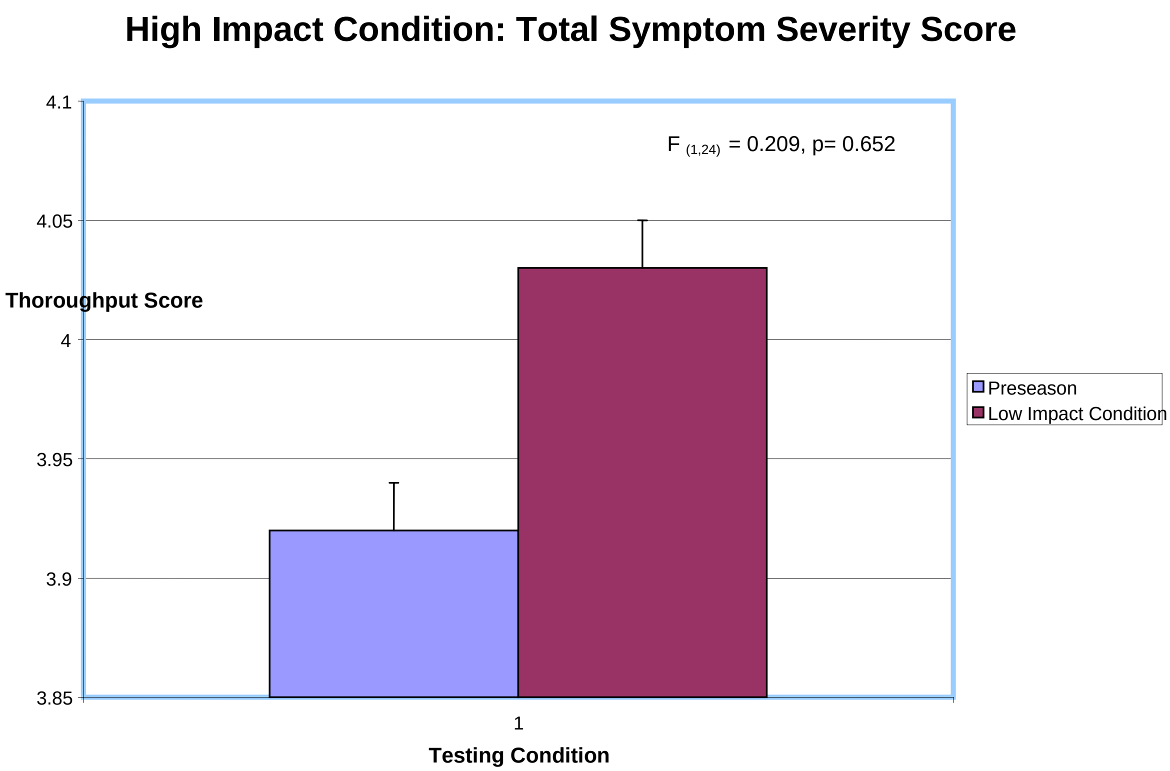

High Impact Condition: Total Symptom Severity Score
F (1,24) = 0.209, p= 0.652
Thoroughput Score
4.1
4.05
4
3.95
3.9
3.85
1
Testing Condition
Preseason
Low Impact Condition

Figure 30

Low Impact Condition: Total # of Symptoms Reported

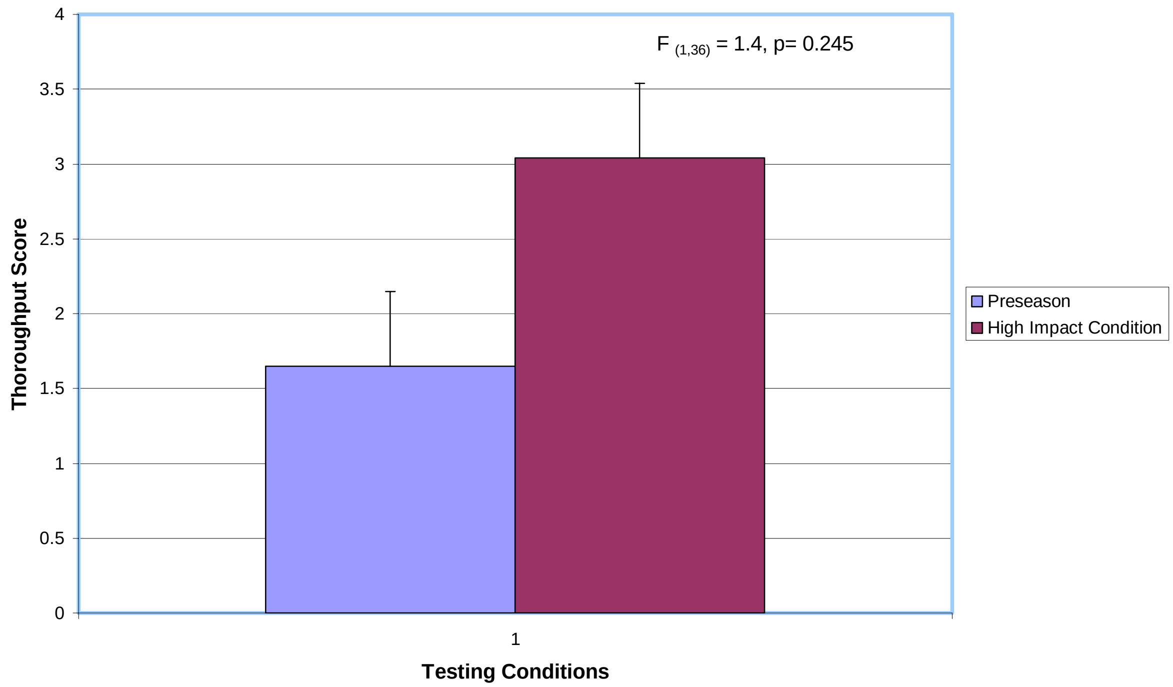
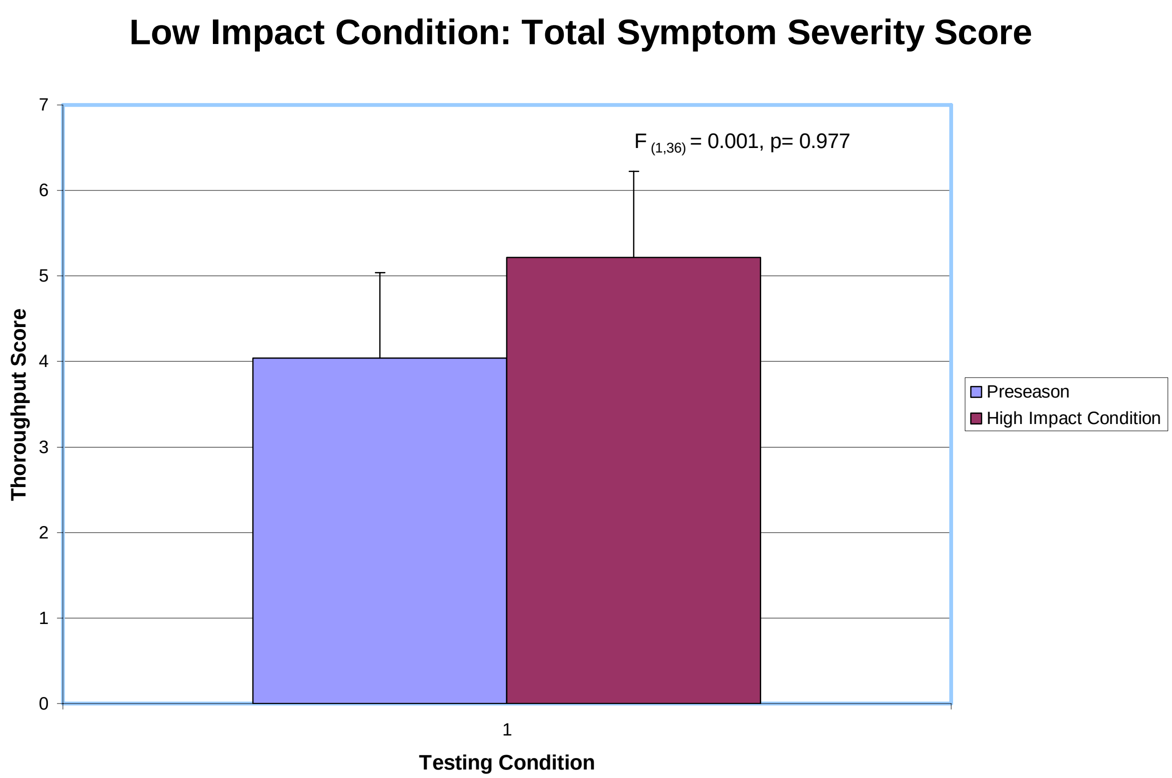
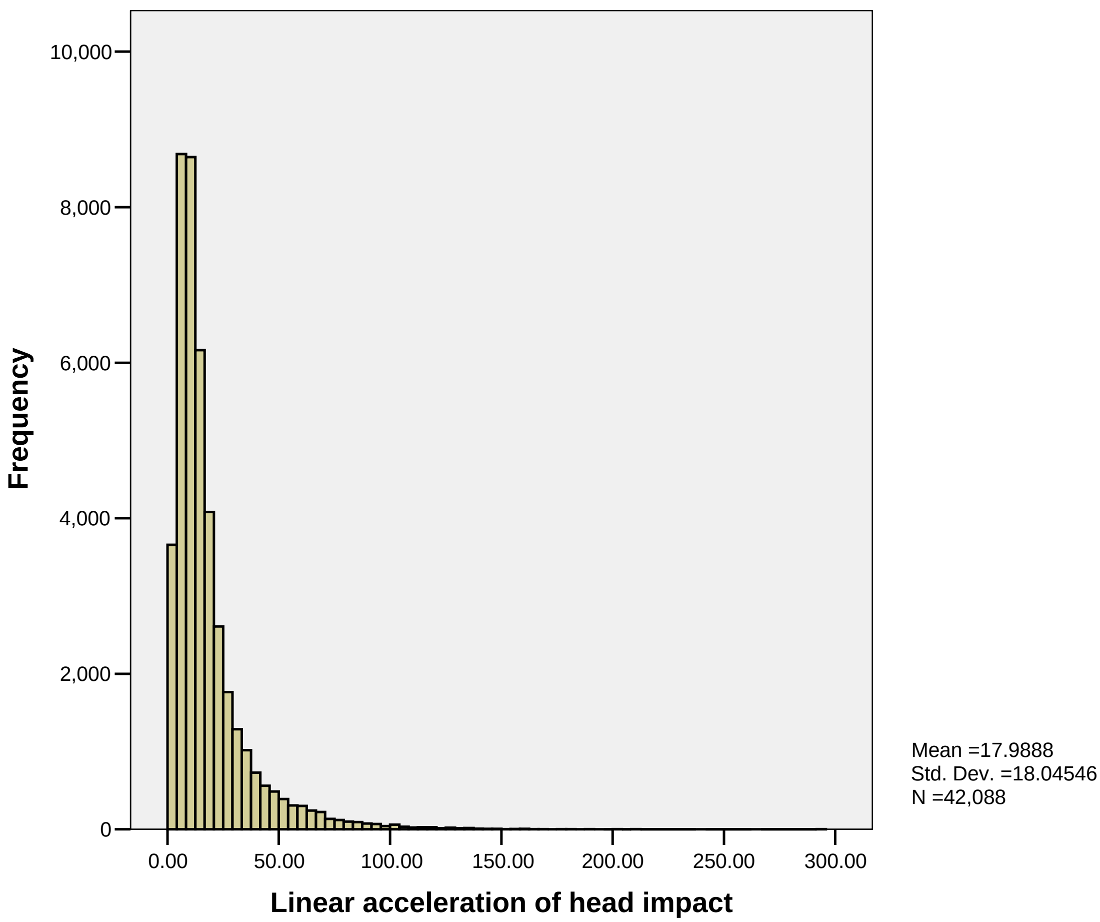


Figure 31



Low Impact Condition: Total Symptom Severity Score
$F_{(1,36)}$ = 0.001, p= 0.977
Thoroughput Score
0
1
2
3
4
5
6
7
1
Testing Condition
Preseason
High Impact Condition

Figure 32



10,000
8,000
6,000
4,000
2,000
0
Frequency
0.00
50.00
100.00
150.00
200.00
250.00
300.00
Linear acceleration of head impact
Mean =17.9888
Std. Dev. =18.04546
N =42,088

Figure 33

APPENDIX D

Testing Schedule

AUGUST 2005

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1 Baseline testing completed	2	3	4	5 **HITS** arrives	6
7	8 helmet installations	9	10 athletes report	11 camp begins	12	13
14 Baseline completed for freshmen	15 testing begins	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

SEPTEMBER 2005

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1	2	3
4	5	6	7	8	9	10 @ GA TECH
11	12	13	14	15	16	17 WISCONSIN
18	19	20	21	22	23	24 @ NC STATE
25	26	27	28	29	30	

Holidays and observances: 5: Labor Day

OCTOBER 2005

Sun	Mon	Tue	Wed	Thu	Fri	Sat
						1 UTAH
2	3	4	5	6	7	8 @ LOUISVILLE
9	10	11	12	13	14	15
16	17	18	19	20	21	22 VIRGINIA
23	24	25	26	27	28	29 @ MIAMI
30	31					

Holidays and observances: 10: Columbus Day

NOVEMBER 2005

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1	2	3	4	5 BC
6	7	8	9	10	11	12 MARYLAND
13	14	15	16	17	18	19 DUKE
20	21	22	23	24	25	26 @ VA TECH
27	28	29	30			

Holidays and observances: 11: Veterans Day, 24: Thanksgiving Day

MARCH 2005

Sun	Mon	Tue	Wed	Thu	Fri	Sat
			1	2	3 testing begins	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29 testing ends	30	31	1

APPENDIX E

SPSS Output

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsrt1
2	t1srt1

Descriptive Statistics

	Mean	Std. Deviation	N
baseline simple reaction time1	237.3446	35.93402	24
test session 1 simple reaction time 1	248.3754	29.88646	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	309.062	1	309.062	.492	.491
	Greenhouse-Geisser	309.062	1.000	309.062	.492	.491
	Huynh-Feldt	309.062	1.000	309.062	.492	.491
	Lower-bound	309.062	1.000	309.062	.492	.491
session * cov1	Sphericity Assumed	29.715	1	29.715	.047	.830
	Greenhouse-Geisser	29.715	1.000	29.715	.047	.830
	Huynh-Feldt	29.715	1.000	29.715	.047	.830
	Lower-bound	29.715	1.000	29.715	.047	.830
session * cov2	Sphericity Assumed	.131	1	.131	.000	.989
	Greenhouse-Geisser	.131	1.000	.131	.000	.989
	Huynh-Feldt	.131	1.000	.131	.000	.989
	Lower-bound	.131	1.000	.131	.000	.989
Error(session)	Sphericity Assumed	13182.866	21	627.756		
	Greenhouse-Geisser	13182.866	21.000	627.756		
	Huynh-Feldt	13182.866	21.000	627.756		
	Lower-bound	13182.866	21.000	627.756		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsrt1
2	t1srt1

Descriptive Statistics

	Mean	Std. Deviation	N
baseline simple reaction time1	236.0860	35.73587	25
test session 1 simple reaction time 1	248.3716	29.25721	25

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	1886.700	1	1886.700	3.298	.082
	Greenhouse-Geisser	1886.700	1.000	1886.700	3.298	.082
	Huynh-Feldt	1886.700	1.000	1886.700	3.298	.082
	Lower-bound	1886.700	1.000	1886.700	3.298	.082
Error(session)	Sphericity Assumed	13729.637	24	572.068		
	Greenhouse-Geisser	13729.637	24.000	572.068		
	Huynh-Feldt	13729.637	24.000	572.068		
	Lower-bound	13729.637	24.000	572.068		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsrt2
2	t1srt2

Descriptive Statistics

	Mean	Std. Deviation	N
basline simple reaction time 2	229.6704	47.04461	24
test session 1 simple reaction time 2	228.8529	51.39511	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	74.284	1	74.284	.068	.796
	Greenhouse-Geisser	74.284	1.000	74.284	.068	.796
	Huynh-Feldt	74.284	1.000	74.284	.068	.796
	Lower-bound	74.284	1.000	74.284	.068	.796
session * cov1	Sphericity Assumed	663.537	1	663.537	.611	.443
	Greenhouse-Geisser	663.537	1.000	663.537	.611	.443
	Huynh-Feldt	663.537	1.000	663.537	.611	.443
	Lower-bound	663.537	1.000	663.537	.611	.443
session * cov2	Sphericity Assumed	584.680	1	584.680	.538	.471
	Greenhouse-Geisser	584.680	1.000	584.680	.538	.471
	Huynh-Feldt	584.680	1.000	584.680	.538	.471
	Lower-bound	584.680	1.000	584.680	.538	.471
Error(session)	Sphericity Assumed	22822.394	21	1086.781		
	Greenhouse-Geisser	22822.394	21.000	1086.781		
	Huynh-Feldt	22822.394	21.000	1086.781		
	Lower-bound	22822.394	21.000	1086.781		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsrt2
2	t1srt2

Descriptive Statistics

	Mean	Std. Deviation	N
basline simple reaction time 2	230.7676	46.37967	25
test session 1 simple reaction time 2	229.9424	50.60702	25

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	8.512	1	8.512	.009	.927
	Greenhouse-Geisser	8.512	1.000	8.512	.009	.927
	Huynh-Feldt	8.512	1.000	8.512	.009	.927
	Lower-bound	8.512	1.000	8.512	.009	.927
Error(session)	Sphericity Assumed	23540.735	24	980.864		
	Greenhouse-Geisser	23540.735	24.000	980.864		
	Huynh-Feldt	23540.735	24.000	980.864		
	Lower-bound	23540.735	24.000	980.864		

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	93.077	1	93.077	17.040	.000
	Greenhouse-Geisser	93.077	1.000	93.077	17.040	.000
	Huynh-Feldt	93.077	1.000	93.077	17.040	.000
	Lower-bound	93.077	1.000	93.077	17.040	.000
session * cov1	Sphericity Assumed	11.248	1	11.248	2.059	.166
	Greenhouse-Geisser	11.248	1.000	11.248	2.059	.166
	Huynh-Feldt	11.248	1.000	11.248	2.059	.166
	Lower-bound	11.248	1.000	11.248	2.059	.166
session * cov2	Sphericity Assumed	.648	1	.648	.119	.734
	Greenhouse-Geisser	.648	1.000	.648	.119	.734
	Huynh-Feldt	.648	1.000	.648	.119	.734
	Lower-bound	.648	1.000	.648	.119	.734
Error(session)	Sphericity Assumed	114.707	21	5.462		
	Greenhouse-Geisser	114.707	21.000	5.462		
	Huynh-Feldt	114.707	21.000	5.462		
	Lower-bound	114.707	21.000	5.462		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsrt2
2	t1srt2

Descriptive Statistics

	Mean	Std. Deviation	N
basline simple reaction time 2	230.7676	46.37967	25
test session 1 simple reaction time 2	229.9424	50.60702	25

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	8.512	1	8.512	.009	.927
	Greenhouse-Geisser	8.512	1.000	8.512	.009	.927
	Huynh-Feldt	8.512	1.000	8.512	.009	.927
	Lower-bound	8.512	1.000	8.512	.009	.927
Error(session)	Sphericity Assumed	23540.735	24	980.864		
	Greenhouse-Geisser	23540.735	24.000	980.864		
	Huynh-Feldt	23540.735	24.000	980.864		
	Lower-bound	23540.735	24.000	980.864		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blmth
2	t1mth

Descriptive Statistics

	Mean	Std. Deviation	N
baseline math processing	20.5829	5.98786	24
test session 1 math processing	23.5554	7.23841	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	93.077	1	93.077	17.040	.000
	Greenhouse-Geisser	93.077	1.000	93.077	17.040	.000
	Huynh-Feldt	93.077	1.000	93.077	17.040	.000
	Lower-bound	93.077	1.000	93.077	17.040	.000
session * cov1	Sphericity Assumed	11.248	1	11.248	2.059	.166
	Greenhouse-Geisser	11.248	1.000	11.248	2.059	.166
	Huynh-Feldt	11.248	1.000	11.248	2.059	.166
	Lower-bound	11.248	1.000	11.248	2.059	.166
session * cov2	Sphericity Assumed	.648	1	.648	.119	.734
	Greenhouse-Geisser	.648	1.000	.648	.119	.734
	Huynh-Feldt	.648	1.000	.648	.119	.734
	Lower-bound	.648	1.000	.648	.119	.734
Error(session)	Sphericity Assumed	114.707	21	5.462		
	Greenhouse-Geisser	114.707	21.000	5.462		
	Huynh-Feldt	114.707	21.000	5.462		
	Lower-bound	114.707	21.000	5.462		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blmth
2	t1mth

Descriptive Statistics

	Mean	Std. Deviation	N
baseline math processing	20.6488	5.87104	25
test session 1 math processing	23.8604	7.24823	25

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	128.930	1	128.930	20.671	.000
	Greenhouse-Geisser	128.930	1.000	128.930	20.671	.000
	Huynh-Feldt	128.930	1.000	128.930	20.671	.000
	Lower-bound	128.930	1.000	128.930	20.671	.000
Error(session)	Sphericity Assumed	149.692	24	6.237		
	Greenhouse-Geisser	149.692	24.000	6.237		
	Huynh-Feldt	149.692	24.000	6.237		
	Lower-bound	149.692	24.000	6.237		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blmts
2	t1mts

Descriptive Statistics

	Mean	Std. Deviation	N
baseline match to sample	40.3135	13.99346	23
test session 1 match to sample	43.5630	14.48864	23

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	54.208	1	54.208	.498	.488
	Greenhouse-Geisser	54.208	1.000	54.208	.498	.488
	Huynh-Feldt	54.208	1.000	54.208	.498	.488
	Lower-bound	54.208	1.000	54.208	.498	.488
session * cov1	Sphericity Assumed	189.411	1	189.411	1.741	.202
	Greenhouse-Geisser	189.411	1.000	189.411	1.741	.202
	Huynh-Feldt	189.411	1.000	189.411	1.741	.202
	Lower-bound	189.411	1.000	189.411	1.741	.202
session * cov2	Sphericity Assumed	4.201	1	4.201	.039	.846
	Greenhouse-Geisser	4.201	1.000	4.201	.039	.846
	Huynh-Feldt	4.201	1.000	4.201	.039	.846
	Lower-bound	4.201	1.000	4.201	.039	.846
Error(session)	Sphericity Assumed	2175.894	20	108.795		
	Greenhouse-Geisser	2175.894	20.000	108.795		
	Huynh-Feldt	2175.894	20.000	108.795		
	Lower-bound	2175.894	20.000	108.795		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blmts
2	t1mts

Descriptive Statistics

	Mean	Std. Deviation	N
baseline match to sample	40.6600	13.79076	24
test session 1 match to sample	43.2800	14.23785	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	82.373	1	82.373	.721	.405
	Greenhouse-Geisser	82.373	1.000	82.373	.721	.405
	Huynh-Feldt	82.373	1.000	82.373	.721	.405
	Lower-bound	82.373	1.000	82.373	.721	.405
Error(session)	Sphericity Assumed	2627.199	23	114.226		
	Greenhouse-Geisser	2627.199	23.000	114.226		
	Huynh-Feldt	2627.199	23.000	114.226		
	Lower-bound	2627.199	23.000	114.226		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blss
2	t1ss

Descriptive Statistics

	Mean	Std. Deviation	N
baseline sleep scale	3.0400	1.51327	25
test session 1 sleep scale	3.8800	1.71561	25

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	8.820	1	8.820	10.756	.003
	Greenhouse-Geisser	8.820	1.000	8.820	10.756	.003
	Huynh-Feldt	8.820	1.000	8.820	10.756	.003
	Lower-bound	8.820	1.000	8.820	10.756	.003
Error(session)	Sphericity Assumed	19.680	24	.820		
	Greenhouse-Geisser	19.680	24.000	.820		
	Huynh-Feldt	19.680	24.000	.820		
	Lower-bound	19.680	24.000	.820		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blprt
2	t1prt

Descriptive Statistics

	Mean	Std. Deviation	N
baseline procedural reaction time	84.8458	17.65716	24
test session 1 procedural reaction time	99.7696	28.34877	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	869.914	1	869.914	1.429	.245
	Greenhouse-Geisser	869.914	1.000	869.914	1.429	.245
	Huynh-Feldt	869.914	1.000	869.914	1.429	.245
	Lower-bound	869.914	1.000	869.914	1.429	.245
session * cov1	Sphericity Assumed	171.712	1	171.712	.282	.601
	Greenhouse-Geisser	171.712	1.000	171.712	.282	.601
	Huynh-Feldt	171.712	1.000	171.712	.282	.601
	Lower-bound	171.712	1.000	171.712	.282	.601
session * cov2	Sphericity Assumed	376.820	1	376.820	.619	.440
	Greenhouse-Geisser	376.820	1.000	376.820	.619	.440
	Huynh-Feldt	376.820	1.000	376.820	.619	.440
	Lower-bound	376.820	1.000	376.820	.619	.440
Error(session)	Sphericity Assumed	12781.519	21	608.644		
	Greenhouse-Geisser	12781.519	21.000	608.644		
	Huynh-Feldt	12781.519	21.000	608.644		
	Lower-bound	12781.519	21.000	608.644		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blcs9
2	cs9

Descriptive Statistics

	Mean	Std. Deviation	N
baseline code sub 9	51.9083	11.20913	24
test session 1 code sub 9	53.3992	7.77197	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	2.412	1	2.412	.027	.870
	Greenhouse-Geisser	2.412	1.000	2.412	.027	.870
	Huynh-Feldt	2.412	1.000	2.412	.027	.870
	Lower-bound	2.412	1.000	2.412	.027	.870
session * cov1	Sphericity Assumed	31.383	1	31.383	.357	.557
	Greenhouse-Geisser	31.383	1.000	31.383	.357	.557
	Huynh-Feldt	31.383	1.000	31.383	.357	.557
	Lower-bound	31.383	1.000	31.383	.357	.557
session * cov2	Sphericity Assumed	74.463	1	74.463	.846	.368
	Greenhouse-Geisser	74.463	1.000	74.463	.846	.368
	Huynh-Feldt	74.463	1.000	74.463	.846	.368
	Lower-bound	74.463	1.000	74.463	.846	.368
Error(session)	Sphericity Assumed	1847.869	21	87.994		
	Greenhouse-Geisser	1847.869	21.000	87.994		
	Huynh-Feldt	1847.869	21.000	87.994		
	Lower-bound	1847.869	21.000	87.994		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blms
2	ms6

Descriptive Statistics

	Mean	Std. Deviation	N
baseline memory search 6	81.1163	13.60006	24
test session memory search 6	85.0213	17.82978	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	16.611	1	16.611	.087	.771
	Greenhouse-Geisser	16.611	1.000	16.611	.087	.771
	Huynh-Feldt	16.611	1.000	16.611	.087	.771
	Lower-bound	16.611	1.000	16.611	.087	.771
session * cov1	Sphericity Assumed	914.569	1	914.569	4.799	.040
	Greenhouse-Geisser	914.569	1.000	914.569	4.799	.040
	Huynh-Feldt	914.569	1.000	914.569	4.799	.040
	Lower-bound	914.569	1.000	914.569	4.799	.040
session * cov2	Sphericity Assumed	552.476	1	552.476	2.899	.103
	Greenhouse-Geisser	552.476	1.000	552.476	2.899	.103
	Huynh-Feldt	552.476	1.000	552.476	2.899	.103
	Lower-bound	552.476	1.000	552.476	2.899	.103
Error(session)	Sphericity Assumed	4002.040	21	190.573		
	Greenhouse-Geisser	4002.040	21.000	190.573		
	Huynh-Feldt	4002.040	21.000	190.573		
	Lower-bound	4002.040	21.000	190.573		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsxitem
2	t1sxitem

Descriptive Statistics

	Mean	Std. Deviation	N
baseline # of symptoms	1.65	2.058	23
test session 1 # symptoms	3.04	2.755	23

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	11.926	1	11.926	3.540	.075
	Greenhouse-Geisser	11.926	1.000	11.926	3.540	.075
	Huynh-Feldt	11.926	1.000	11.926	3.540	.075
	Lower-bound	11.926	1.000	11.926	3.540	.075
session * cov1	Sphericity Assumed	.073	1	.073	.022	.885
	Greenhouse-Geisser	.073	1.000	.073	.022	.885
	Huynh-Feldt	.073	1.000	.073	.022	.885
	Lower-bound	.073	1.000	.073	.022	.885
session * cov2	Sphericity Assumed	.022	1	.022	.007	.936
	Greenhouse-Geisser	.022	1.000	.022	.007	.936
	Huynh-Feldt	.022	1.000	.022	.007	.936
	Lower-bound	.022	1.000	.022	.007	.936
Error(session)	Sphericity Assumed	67.373	20	3.369		
	Greenhouse-Geisser	67.373	20.000	3.369		
	Huynh-Feldt	67.373	20.000	3.369		
	Lower-bound	67.373	20.000	3.369		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsxscor
2	t1sxscor

Descriptive Statistics

	Mean	Std. Deviation	N
baseline symptom score	4.04	5.958	23
test session 1 symptom score	5.22	5.893	23

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	4.737	1	4.737	.209	.652
	Greenhouse-Geisser	4.737	1.000	4.737	.209	.652
	Huynh-Feldt	4.737	1.000	4.737	.209	.652
	Lower-bound	4.737	1.000	4.737	.209	.652
session * cov1	Sphericity Assumed	19.565	1	19.565	.864	.364
	Greenhouse-Geisser	19.565	1.000	19.565	.864	.364
	Huynh-Feldt	19.565	1.000	19.565	.864	.364
	Lower-bound	19.565	1.000	19.565	.864	.364
session * cov2	Sphericity Assumed	26.993	1	26.993	1.191	.288
	Greenhouse-Geisser	26.993	1.000	26.993	1.191	.288
	Huynh-Feldt	26.993	1.000	26.993	1.191	.288
	Lower-bound	26.993	1.000	26.993	1.191	.288
Error(session)	Sphericity Assumed	453.111	20	22.656		
	Greenhouse-Geisser	453.111	20.000	22.656		
	Huynh-Feldt	453.111	20.000	22.656		
	Lower-bound	453.111	20.000	22.656		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsom
2	t1som

Descriptive Statistics

	Mean	Std. Deviation	N
baseline somatosensory	96.6910	2.62263	24
test session 1 somatosensory	98.1808	4.25806	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.596	1	.596	.065	.801
	Greenhouse-Geisser	.596	1.000	.596	.065	.801
	Huynh-Feldt	.596	1.000	.596	.065	.801
	Lower-bound	.596	1.000	.596	.065	.801
session * cov1	Sphericity Assumed	20.294	1	20.294	2.223	.151
	Greenhouse-Geisser	20.294	1.000	20.294	2.223	.151
	Huynh-Feldt	20.294	1.000	20.294	2.223	.151
	Lower-bound	20.294	1.000	20.294	2.223	.151
session * cov2	Sphericity Assumed	1.513	1	1.513	.166	.688
	Greenhouse-Geisser	1.513	1.000	1.513	.166	.688
	Huynh-Feldt	1.513	1.000	1.513	.166	.688
	Lower-bound	1.513	1.000	1.513	.166	.688
Error(session)	Sphericity Assumed	191.704	21	9.129		
	Greenhouse-Geisser	191.704	21.000	9.129		
	Huynh-Feldt	191.704	21.000	9.129		
	Lower-bound	191.704	21.000	9.129		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blvis
2	t1vis

Descriptive Statistics

	Mean	Std. Deviation	N
baseline visual	92.0967	5.65651	24
test session 1 visual	90.0804	11.18863	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	7.346	1	7.346	.101	.754
	Greenhouse-Geisser	7.346	1.000	7.346	.101	.754
	Huynh-Feldt	7.346	1.000	7.346	.101	.754
	Lower-bound	7.346	1.000	7.346	.101	.754
session * cov1	Sphericity Assumed	146.551	1	146.551	2.009	.171
	Greenhouse-Geisser	146.551	1.000	146.551	2.009	.171
	Huynh-Feldt	146.551	1.000	146.551	2.009	.171
	Lower-bound	146.551	1.000	146.551	2.009	.171
session * cov2	Sphericity Assumed	167.105	1	167.105	2.291	.145
	Greenhouse-Geisser	167.105	1.000	167.105	2.291	.145
	Huynh-Feldt	167.105	1.000	167.105	2.291	.145
	Lower-bound	167.105	1.000	167.105	2.291	.145
Error(session)	Sphericity Assumed	1531.753	21	72.941		
	Greenhouse-Geisser	1531.753	21.000	72.941		
	Huynh-Feldt	1531.753	21.000	72.941		
	Lower-bound	1531.753	21.000	72.941		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blvest
2	t1vest

Descriptive Statistics

	Mean	Std. Deviation	N
baseline vestibular	78.0673	10.89173	24
test session vestibular	77.9928	11.01965	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	14.809	1	14.809	.126	.727
	Greenhouse-Geisser	14.809	1.000	14.809	.126	.727
	Huynh-Feldt	14.809	1.000	14.809	.126	.727
	Lower-bound	14.809	1.000	14.809	.126	.727
session * cov1	Sphericity Assumed	72.707	1	72.707	.616	.441
	Greenhouse-Geisser	72.707	1.000	72.707	.616	.441
	Huynh-Feldt	72.707	1.000	72.707	.616	.441
	Lower-bound	72.707	1.000	72.707	.616	.441
session * cov2	Sphericity Assumed	37.957	1	37.957	.322	.577
	Greenhouse-Geisser	37.957	1.000	37.957	.322	.577
	Huynh-Feldt	37.957	1.000	37.957	.322	.577
	Lower-bound	37.957	1.000	37.957	.322	.577
Error(session)	Sphericity Assumed	2476.931	21	117.949		
	Greenhouse-Geisser	2476.931	21.000	117.949		
	Huynh-Feldt	2476.931	21.000	117.949		
	Lower-bound	2476.931	21.000	117.949		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blnccomp
2	t1nccomp

Descriptive Statistics

	Mean	Std. Deviation	N
baseline neurocom compsite	81.3385	5.64698	24
test session 1 neurocom compsite	80.0968	7.66214	24

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.533	1	.533	.015	.905
	Greenhouse-Geisser	.533	1.000	.533	.015	.905
	Huynh-Feldt	.533	1.000	.533	.015	.905
	Lower-bound	.533	1.000	.533	.015	.905
session * cov1	Sphericity Assumed	116.836	1	116.836	3.189	.089
	Greenhouse-Geisser	116.836	1.000	116.836	3.189	.089
	Huynh-Feldt	116.836	1.000	116.836	3.189	.089
	Lower-bound	116.836	1.000	116.836	3.189	.089
session * cov2	Sphericity Assumed	90.637	1	90.637	2.474	.131
	Greenhouse-Geisser	90.637	1.000	90.637	2.474	.131
	Huynh-Feldt	90.637	1.000	90.637	2.474	.131
	Lower-bound	90.637	1.000	90.637	2.474	.131
Error(session)	Sphericity Assumed	769.454	21	36.641		
	Greenhouse-Geisser	769.454	21.000	36.641		
	Huynh-Feldt	769.454	21.000	36.641		
	Lower-bound	769.454	21.000	36.641		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsrt1
2	t2srt1

Descriptive Statistics

	Mean	Std. Deviation	N
baseline simple reaction time1	238.8861	33.57134	36
test session 2 simple reaction 1	252.9186	28.26507	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	4528.973	1	4528.973	6.012	.020
	Greenhouse-Geisser	4528.973	1.000	4528.973	6.012	.020
	Huynh-Feldt	4528.973	1.000	4528.973	6.012	.020
	Lower-bound	4528.973	1.000	4528.973	6.012	.020
session * cov3	Sphericity Assumed	77.321	1	77.321	.103	.751
	Greenhouse-Geisser	77.321	1.000	77.321	.103	.751
	Huynh-Feldt	77.321	1.000	77.321	.103	.751
	Lower-bound	77.321	1.000	77.321	.103	.751
session * cov4	Sphericity Assumed	234.644	1	234.644	.311	.581
	Greenhouse-Geisser	234.644	1.000	234.644	.311	.581
	Huynh-Feldt	234.644	1.000	234.644	.311	.581
	Lower-bound	234.644	1.000	234.644	.311	.581
Error(session)	Sphericity Assumed	24858.418	33	753.285		
	Greenhouse-Geisser	24858.418	33.000	753.285		
	Huynh-Feldt	24858.418	33.000	753.285		
	Lower-bound	24858.418	33.000	753.285		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsrt2
2	t2srt2

Descriptive Statistics

	Mean	Std. Deviation	N
basline simple reaction time 2	233.3494	42.34026	36
test session 2 simple reaction 2	237.0100	33.71660	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	1258.631	1	1258.631	.943	.338
	Greenhouse-Geisser	1258.631	1.000	1258.631	.943	.338
	Huynh-Feldt	1258.631	1.000	1258.631	.943	.338
	Lower-bound	1258.631	1.000	1258.631	.943	.338
session * cov3	Sphericity Assumed	.012	1	.012	.000	.998
	Greenhouse-Geisser	.012	1.000	.012	.000	.998
	Huynh-Feldt	.012	1.000	.012	.000	.998
	Lower-bound	.012	1.000	.012	.000	.998
session * cov4	Sphericity Assumed	500.950	1	500.950	.376	.544
	Greenhouse-Geisser	500.950	1.000	500.950	.376	.544
	Huynh-Feldt	500.950	1.000	500.950	.376	.544
	Lower-bound	500.950	1.000	500.950	.376	.544
Error(session)	Sphericity Assumed	44022.284	33	1334.009		
	Greenhouse-Geisser	44022.284	33.000	1334.009		
	Huynh-Feldt	44022.284	33.000	1334.009		
	Lower-bound	44022.284	33.000	1334.009		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blmth
2	t2mth

Descriptive Statistics

	Mean	Std. Deviation	N
baseline math processing	20.4486	6.11066	36
test session 2 math processing	22.6258	6.60505	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	59.911	1	59.911	10.584	.003
	Greenhouse-Geisser	59.911	1.000	59.911	10.584	.003
	Huynh-Feldt	59.911	1.000	59.911	10.584	.003
	Lower-bound	59.911	1.000	59.911	10.584	.003
session * cov3	Sphericity Assumed	1.104	1	1.104	.195	.662
	Greenhouse-Geisser	1.104	1.000	1.104	.195	.662
	Huynh-Feldt	1.104	1.000	1.104	.195	.662
	Lower-bound	1.104	1.000	1.104	.195	.662
session * cov4	Sphericity Assumed	5.991	1	5.991	1.058	.311
	Greenhouse-Geisser	5.991	1.000	5.991	1.058	.311
	Huynh-Feldt	5.991	1.000	5.991	1.058	.311
	Lower-bound	5.991	1.000	5.991	1.058	.311
Error(session)	Sphericity Assumed	186.800	33	5.661		
	Greenhouse-Geisser	186.800	33.000	5.661		
	Huynh-Feldt	186.800	33.000	5.661		
	Lower-bound	186.800	33.000	5.661		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blmts
2	t2mts

Descriptive Statistics

	Mean	Std. Deviation	N
baseline match to sample	40.4867	13.38647	36
test session 2 match to sample	47.8522	13.21119	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	212.502	1	212.502	2.129	.154
	Greenhouse-Geisser	212.502	1.000	212.502	2.129	.154
	Huynh-Feldt	212.502	1.000	212.502	2.129	.154
	Lower-bound	212.502	1.000	212.502	2.129	.154
session * cov3	Sphericity Assumed	11.519	1	11.519	.115	.736
	Greenhouse-Geisser	11.519	1.000	11.519	.115	.736
	Huynh-Feldt	11.519	1.000	11.519	.115	.736
	Lower-bound	11.519	1.000	11.519	.115	.736
session * cov4	Sphericity Assumed	5.431	1	5.431	.054	.817
	Greenhouse-Geisser	5.431	1.000	5.431	.054	.817
	Huynh-Feldt	5.431	1.000	5.431	.054	.817
	Lower-bound	5.431	1.000	5.431	.054	.817
Error(session)	Sphericity Assumed	3293.686	33	99.809		
	Greenhouse-Geisser	3293.686	33.000	99.809		
	Huynh-Feldt	3293.686	33.000	99.809		
	Lower-bound	3293.686	33.000	99.809		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blss
2	t2ss

Descriptive Statistics

	Mean	Std. Deviation	N
baseline sleep scale	2.9722	1.66452	36
test session 2 sleep scale	3.0556	1.41309	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	4.103	1	4.103	3.765	.061
	Greenhouse-Geisser	4.103	1.000	4.103	3.765	.061
	Huynh-Feldt	4.103	1.000	4.103	3.765	.061
	Lower-bound	4.103	1.000	4.103	3.765	.061
session * cov3	Sphericity Assumed	1.480	1	1.480	1.358	.252
	Greenhouse-Geisser	1.480	1.000	1.480	1.358	.252
	Huynh-Feldt	1.480	1.000	1.480	1.358	.252
	Lower-bound	1.480	1.000	1.480	1.358	.252
session * cov4	Sphericity Assumed	.604	1	.604	.554	.462
	Greenhouse-Geisser	.604	1.000	.604	.554	.462
	Huynh-Feldt	.604	1.000	.604	.554	.462
	Lower-bound	.604	1.000	.604	.554	.462
Error(session)	Sphericity Assumed	35.966	33	1.090		
	Greenhouse-Geisser	35.966	33.000	1.090		
	Huynh-Feldt	35.966	33.000	1.090		
	Lower-bound	35.966	33.000	1.090		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blprt
2	t2prt

Descriptive Statistics

	Mean	Std. Deviation	N
baseline procedural reaction time	88.5028	17.57839	36
test session 2 procedural reaction time	97.2744	23.16368	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	246.473	1	246.473	.758	.390
	Greenhouse-Geisser	246.473	1.000	246.473	.758	.390
	Huynh-Feldt	246.473	1.000	246.473	.758	.390
	Lower-bound	246.473	1.000	246.473	.758	.390
session * cov3	Sphericity Assumed	54.112	1	54.112	.166	.686
	Greenhouse-Geisser	54.112	1.000	54.112	.166	.686
	Huynh-Feldt	54.112	1.000	54.112	.166	.686
	Lower-bound	54.112	1.000	54.112	.166	.686
session * cov4	Sphericity Assumed	258.401	1	258.401	.794	.379
	Greenhouse-Geisser	258.401	1.000	258.401	.794	.379
	Huynh-Feldt	258.401	1.000	258.401	.794	.379
	Lower-bound	258.401	1.000	258.401	.794	.379
Error(session)	Sphericity Assumed	10733.655	33	325.262		
	Greenhouse-Geisser	10733.655	33.000	325.262		
	Huynh-Feldt	10733.655	33.000	325.262		
	Lower-bound	10733.655	33.000	325.262		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blcs9
2	t2cs9

Descriptive Statistics

	Mean	Std. Deviation	N
baseline code sub 9	51.6456	11.39935	36
test session 2 code sub 9	55.3775	9.58960	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	275.378	1	275.378	4.836	.035
	Greenhouse-Geisser	275.378	1.000	275.378	4.836	.035
	Huynh-Feldt	275.378	1.000	275.378	4.836	.035
	Lower-bound	275.378	1.000	275.378	4.836	.035
session * cov3	Sphericity Assumed	51.587	1	51.587	.906	.348
	Greenhouse-Geisser	51.587	1.000	51.587	.906	.348
	Huynh-Feldt	51.587	1.000	51.587	.906	.348
	Lower-bound	51.587	1.000	51.587	.906	.348
session * cov4	Sphericity Assumed	162.880	1	162.880	2.860	.100
	Greenhouse-Geisser	162.880	1.000	162.880	2.860	.100
	Huynh-Feldt	162.880	1.000	162.880	2.860	.100
	Lower-bound	162.880	1.000	162.880	2.860	.100
Error(session)	Sphericity Assumed	1879.265	33	56.947		
	Greenhouse-Geisser	1879.265	33.000	56.947		
	Huynh-Feldt	1879.265	33.000	56.947		
	Lower-bound	1879.265	33.000	56.947		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blms
2	t2ms6

Descriptive Statistics

	Mean	Std. Deviation	N
baseline memory search 6	79.0969	16.94917	36
test session 2 memory search 6	89.7181	19.11151	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	1320.820	1	1320.820	5.402	.026
	Greenhouse-Geisser	1320.820	1.000	1320.820	5.402	.026
	Huynh-Feldt	1320.820	1.000	1320.820	5.402	.026
	Lower-bound	1320.820	1.000	1320.820	5.402	.026
session * cov3	Sphericity Assumed	16.496	1	16.496	.067	.797
	Greenhouse-Geisser	16.496	1.000	16.496	.067	.797
	Huynh-Feldt	16.496	1.000	16.496	.067	.797
	Lower-bound	16.496	1.000	16.496	.067	.797
session * cov4	Sphericity Assumed	91.458	1	91.458	.374	.545
	Greenhouse-Geisser	91.458	1.000	91.458	.374	.545
	Huynh-Feldt	91.458	1.000	91.458	.374	.545
	Lower-bound	91.458	1.000	91.458	.374	.545
Error(session)	Sphericity Assumed	8068.651	33	244.505		
	Greenhouse-Geisser	8068.651	33.000	244.505		
	Huynh-Feldt	8068.651	33.000	244.505		
	Lower-bound	8068.651	33.000	244.505		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsxitem
2	t2sxitem

Descriptive Statistics

	Mean	Std. Deviation	N
baseline # of symptoms	1.81	2.436	36
test session 2 # of symptoms	2.61	2.567	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	8.285	1	8.285	1.400	.245
	Greenhouse-Geisser	8.285	1.000	8.285	1.400	.245
	Huynh-Feldt	8.285	1.000	8.285	1.400	.245
	Lower-bound	8.285	1.000	8.285	1.400	.245
session * cov3	Sphericity Assumed	1.447	1	1.447	.245	.624
	Greenhouse-Geisser	1.447	1.000	1.447	.245	.624
	Huynh-Feldt	1.447	1.000	1.447	.245	.624
	Lower-bound	1.447	1.000	1.447	.245	.624
session * cov4	Sphericity Assumed	.533	1	.533	.090	.766
	Greenhouse-Geisser	.533	1.000	.533	.090	.766
	Huynh-Feldt	.533	1.000	.533	.090	.766
	Lower-bound	.533	1.000	.533	.090	.766
Error(session)	Sphericity Assumed	195.248	33	5.917		
	Greenhouse-Geisser	195.248	33.000	5.917		
	Huynh-Feldt	195.248	33.000	5.917		
	Lower-bound	195.248	33.000	5.917		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsxscor
2	t2sxscor

Descriptive Statistics

	Mean	Std. Deviation	N
baseline symptom score	3.92	6.583	36
test session 2 score of symptoms	4.03	4.582	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.029	1	.029	.001	.977
	Greenhouse-Geisser	.029	1.000	.029	.001	.977
	Huynh-Feldt	.029	1.000	.029	.001	.977
	Lower-bound	.029	1.000	.029	.001	.977
session * cov3	Sphericity Assumed	1.979	1	1.979	.057	.813
	Greenhouse-Geisser	1.979	1.000	1.979	.057	.813
	Huynh-Feldt	1.979	1.000	1.979	.057	.813
	Lower-bound	1.979	1.000	1.979	.057	.813
session * cov4	Sphericity Assumed	3.595	1	3.595	.103	.750
	Greenhouse-Geisser	3.595	1.000	3.595	.103	.750
	Huynh-Feldt	3.595	1.000	3.595	.103	.750
	Lower-bound	3.595	1.000	3.595	.103	.750
Error(session)	Sphericity Assumed	1153.163	33	34.944		
	Greenhouse-Geisser	1153.163	33.000	34.944		
	Huynh-Feldt	1153.163	33.000	34.944		
	Lower-bound	1153.163	33.000	34.944		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blsom
2	t2som

Descriptive Statistics

	Mean	Std. Deviation	N
baseline somatosensory	97.0900	2.82393	36
test session 2 somatosensory	96.0252	3.50081	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	8.538	1	8.538	1.000	.325
	Greenhouse-Geisser	8.538	1.000	8.538	1.000	.325
	Huynh-Feldt	8.538	1.000	8.538	1.000	.325
	Lower-bound	8.538	1.000	8.538	1.000	.325
session * cov3	Sphericity Assumed	5.480	1	5.480	.642	.429
	Greenhouse-Geisser	5.480	1.000	5.480	.642	.429
	Huynh-Feldt	5.480	1.000	5.480	.642	.429
	Lower-bound	5.480	1.000	5.480	.642	.429
session * cov4	Sphericity Assumed	5.347	1	5.347	.626	.434
	Greenhouse-Geisser	5.347	1.000	5.347	.626	.434
	Huynh-Feldt	5.347	1.000	5.347	.626	.434
	Lower-bound	5.347	1.000	5.347	.626	.434
Error(session)	Sphericity Assumed	281.762	33	8.538		
	Greenhouse-Geisser	281.762	33.000	8.538		
	Huynh-Feldt	281.762	33.000	8.538		
	Lower-bound	281.762	33.000	8.538		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blvis
2	t2vis

Descriptive Statistics

	Mean	Std. Deviation	N
baseline visual	92.0163	6.19000	36
test session 2 visual	90.0501	10.87690	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	213.784	1	213.784	4.052	.052
	Greenhouse-Geisser	213.784	1.000	213.784	4.052	.052
	Huynh-Feldt	213.784	1.000	213.784	4.052	.052
	Lower-bound	213.784	1.000	213.784	4.052	.052
session * cov3	Sphericity Assumed	447.951	1	447.951	8.489	.006
	Greenhouse-Geisser	447.951	1.000	447.951	8.489	.006
	Huynh-Feldt	447.951	1.000	447.951	8.489	.006
	Lower-bound	447.951	1.000	447.951	8.489	.006
session * cov4	Sphericity Assumed	13.721	1	13.721	.260	.613
	Greenhouse-Geisser	13.721	1.000	13.721	.260	.613
	Huynh-Feldt	13.721	1.000	13.721	.260	.613
	Lower-bound	13.721	1.000	13.721	.260	.613
Error(session)	Sphericity Assumed	1741.255	33	52.765		
	Greenhouse-Geisser	1741.255	33.000	52.765		
	Huynh-Feldt	1741.255	33.000	52.765		
	Lower-bound	1741.255	33.000	52.765		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blvest
2	t2vest

Descriptive Statistics

	Mean	Std. Deviation	N
baseline vestibular	76.9210	11.51643	36
test session 2 vestibular	79.8029	8.81868	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	558.648	1	558.648	8.677	.006
	Greenhouse-Geisser	558.648	1.000	558.648	8.677	.006
	Huynh-Feldt	558.648	1.000	558.648	8.677	.006
	Lower-bound	558.648	1.000	558.648	8.677	.006
session * cov3	Sphericity Assumed	860.196	1	860.196	13.360	.001
	Greenhouse-Geisser	860.196	1.000	860.196	13.360	.001
	Huynh-Feldt	860.196	1.000	860.196	13.360	.001
	Lower-bound	860.196	1.000	860.196	13.360	.001
session * cov4	Sphericity Assumed	273.253	1	273.253	4.244	.047
	Greenhouse-Geisser	273.253	1.000	273.253	4.244	.047
	Huynh-Feldt	273.253	1.000	273.253	4.244	.047
	Lower-bound	273.253	1.000	273.253	4.244	.047
Error(session)	Sphericity Assumed	2124.738	33	64.386		
	Greenhouse-Geisser	2124.738	33.000	64.386		
	Huynh-Feldt	2124.738	33.000	64.386		
	Lower-bound	2124.738	33.000	64.386		

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	blnccomp
2	t2nccomp

Descriptive Statistics

	Mean	Std. Deviation	N
baseline neurocom compsite	81.2124	5.44771	36
test session 2 neurocom composite	81.7563	7.22218	36

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	263.112	1	263.112	12.754	.001
	Greenhouse-Geisser	263.112	1.000	263.112	12.754	.001
	Huynh-Feldt	263.112	1.000	263.112	12.754	.001
	Lower-bound	263.112	1.000	263.112	12.754	.001
session * cov3	Sphericity Assumed	182.740	1	182.740	8.858	.005
	Greenhouse-Geisser	182.740	1.000	182.740	8.858	.005
	Huynh-Feldt	182.740	1.000	182.740	8.858	.005
	Lower-bound	182.740	1.000	182.740	8.858	.005
session * cov4	Sphericity Assumed	.651	1	.651	.032	.860
	Greenhouse-Geisser	.651	1.000	.651	.032	.860
	Huynh-Feldt	.651	1.000	.651	.032	.860
	Lower-bound	.651	1.000	.651	.032	.860
Error(session)	Sphericity Assumed	680.757	33	20.629		
	Greenhouse-Geisser	680.757	33.000	20.629		
	Huynh-Feldt	680.757	33.000	20.629		
	Lower-bound	680.757	33.000	20.629		

APPENDIX F

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EFFECTS OF HIGH AND LOW IMPACT MAGNITUDE ON CONCUSSION MEASURES IN COLLEGIATE FOOTBALL PLAYERS

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Effects of High and Low Impact Magnitudes on Concussion Measures in Collegiate Football Players

Context: Concussion remains a topic of interest for sports medicine professionals. There is speculation that high-magnitude impacts result in concussive injuries. It has been speculated that a theoretical injury threshold for mild traumatic brain injuries of 98 g exists.

Objective: To investigate how balance and neurocognitive performance are affected by head impacts exceeding a theoretical injury threshold in the absence of self-reported symptoms.

Design: Participants completed a series of balance and neuropsychological tests using a double-blind, repeated measures design.

Settings: Sports Medicine Research Laboratory.

Patients or Other Participants: Forty-three Division I collegiate football players.

Interventions: Subjects participated in three test sessions (baseline, low-impact, and high-impact) separated by at least two weeks. Participants were selected for participation based on the magnitudes of the head impacts they sustained in a given practice or game session.

Main Outcome Measure(s): The Head Impact Telemetry (HIT) System was used to record real-time head impacts sustained in practices and games. The Automated Neuropsychological Assessment Metrics (ANAM) was used to assess neurocognitive performance. The NeuroCom Sensory Organization Test (SOT) was used to assess postural stability. The Graded Symptom Checklist (GSC) was used to assess symptom presence and severity in our participants.

Results: Significant differences were found in the low test conditions ($F_{(1,36)}$=.8.677, p=.006) for SOT vestibular scores, whereby the score improved after the low impact magnitude testing. In addition, the composite score ($F_{(1,36)}$ = 12.754, p=.001) for the low impact condition increased when compared to the baseline measures. No differences were found among any other conditions for SOT ratio scores. Observable improvements in the math processing subtest of ANAM ($F_{1,24}$=17.04, $p<.001$); ($F_{1,36}$=10.584, p=.003); simple reaction time ($F_{(1, 36)}$=6.012, p=.02), code sub 9 ($F_{(1, 36)}$=4.836, p=.035) and memory search 6 ($F_{(1, 36)}$=.5.402, p=.026) were likely attributed to a learning effect. No differences were observed in any other ANAM subtest, or for the GSC severity score or the number of symptoms endorsed.

Conclusions: Our findings suggest that sustaining an impact greater than 100 g does not result in acute observable balance and neurocognitive deficits within 24 hours of sustaining the impact. Although previous studies have suggested a theoretical injury threshold, none have been founded on empirical data collected in real-time on the playing field. Future studies should consider the cumulative effects of impacts of varying magnitudes.

Key Words: mild traumatic brain injury, head impact telemetry system, concussive injury threshold, concussion

INTRODUCTION

Mild traumatic brain injuries are of growing concern throughout competitive sports. A mild traumatic brain injury (MTBI) is defined as a traumatically induced alteration in neural function that may or may not involve loss of consciousness.(Collins, Grindel et al. 1999) Despite the amount of research being conducted in the field of sports-related MTBI, much is still unknown about the injury. An estimated 300,000 sports-related MTBI's are reported each year in the United States among children, adolescents, and young adults.(1997) Published research has promoted improvements in equipment, and changes in rules have been introduced in an attempt to reduce the incidence of MTBI among a continually growing athletic population.(Mueller 2001) Despite the improvements to facial and head protection, and the implementation of new rule changes, the number of athletes that sustain MTBI's remains high throughout athletics.(McCrea, Guskiewicz et al. 2003)

There is arguably no gold standard for managing MTBI. Over 20 grading scales and return to play guidelines have been presented in the literature, although none have been empirically supported. American football, often categorized as a high risk contact sport, is one of the most commonly studied sports in the sports-related MTBI research model since athletes have a relatively high incidence of MTBI's. Players repeatedly sustain impacts to the head that are comparable to those sustained in car crashes.(Zhang, Yang et al. 2004) Many MTBI's are underreported and younger athletes are less likely to report his or her symptoms to the certified athletic trainer entrusted with his or her immediate care.(Collins and Hawn 2002) This is due to a number of factors that vary with both sport and athlete. Preventing fatalities from MTBI has always been a goal of the medical field. A need for exploring new methods of better monitoring the impacts an athlete may sustain during participation remains an area of much interest in the sports medicine community. Thus, there is still much to be learned regarding exactly how the impacts that a football athlete sustains on a daily basis affects the brain. Although laboratory testing of head impact biomechanics has become quite advanced, athletic environments offer a rich opportunity for collecting data on large numbers of head impacts sustained by many players. Without this knowledge, clinicians must often resort to the self-report of symptoms by their athletes.

Although a number of symptoms typically follow a MTBI, these symptoms might not present immediately; they often manifest 24 hours after the initial impact suffered. By further examining the location, duration, and magnitude of impacts that football players are sustaining on a daily basis, it has been suggested that the medical personnel will be able to provide better medical care to the athlete in terms of the immediate recognition of injury and the effects it may have on the body. Much is still unknown about the clinical manifestations observed in athletes following measurable impacts greater than previously reported injury thresholds.

The primary purpose of this study was to compare measures of balance performance and neurocognitive function at baseline to those obtained after the participant had sustained an impact to the head with a magnitude of linear acceleration greater than 100 g. The secondary purpose of this study was to compare the measures of balance and neurocognitive function at baseline to those obtained after the participant had sustained an impact to the head with a magnitude of linear acceleration less than 70 g. The overall objective was to observe if there were acute effects of magnitude of head impacts in the participants' balance and neurocognitive performance in the absence of self-reported symptoms.

METHODS

Participants

Forty-three Division I male collegiate football players (20.74 ± 1.62 years old; 110.29 ± 15.78 kg, 73.41± cm) were initially enrolled in this study. Subsequently, 24 players were used in the comparison of scores between impacts greater than 100 g and baseline, while 38 completed testing in the less than 70 g and baseline comparison. Our sample included a variety of playing positions such as: defensive linemen (DL), offensive linemen (OL), wide receivers (WR), linebackers (LB), offensive backs (OB), and defensive backs (DB). Subjects had no medical conditions or injury to the lower extremity within six weeks of testing that may have affected their ability to perform balance tasks. Participants were required to fill out a medical health history questionnaire. Exclusion criteria included previously diagnosed head injury within the last six months, or having a current vestibular, visual, or balance disorder. Participants underwent baseline testing prior to the start of the season. The participants were given a packet with information about the study and what it entailed. All subjects signed the appropriate informed consent form that was approved by the university's institutional review board.

Instrumentation

Head Impact Telemetry (HIT) System

In order to isolate players who had sustained a given impact magnitude, we used the Head Impact Telemetry (HIT) System (Riddell Corp.; Elyria, OH). The HIT System obtained data from accelerometer units comprised of six spring-mounted single-axis accelerometers embedded in Riddell VSR-4 and Revolution football helmets (Riddell Corp.; Elyria, OH). The signal transducer was linked to a laptop computer in the Sideline Response System via radiowave transmission (903-927 MHz). The information was stored on an onboard memory system (up to 100 impacts) or was immediately transferred to the laptop computer system (8 bit, 10000 Hz/channel). The HIT System has the ability to simultaneously monitor a total of 64 players. The downloaded impacts were then processed through a validation algorithm; variables such as peak head linear acceleration, impact location, Gadd Severity Index (GSI), Head Injury Criteria (HIC), sagittal and lateral peak rotational acceleration, were computed. The HIT System was previously validated in laboratory testing with Hybrid dummies equipped with football helmets. (Padgaonkar AJ 1975; DiMasi 1995; Duma, Manoogian et al. 2005)

Sensory Organization Test

The Sensory Organization Test (SOT; NeuroCom International Inc.; Clackamas, OR) was used to assess participants' balance performance during preseason baseline screening, and in both follow-up test sessions. The SOT is able to assess balance performance by disrupting input from the visual, vestibular, and somatosensory systems. The participants stood with feet shoulder width apart on the force platform with arms comfortably at both sides. Participants were asked to complete three 20-second trials of six different sensory conditions in random order. The six testing conditions were as follows: normal vision and normal support surface, eyes closed with normal support surface, sway-referenced visual input with normal support surface, normal vision and sway referenced support surface, eyes closed and sway referenced visual and support surface. The outcome measures represented how much that particular component (visual, vestibular, somatosensory) is contributing to the overall composite score.

Automated Neuropsychological Assessment Metrics

Participants were tested using the Automated Neuropsychological Assessment Metrics (ANAM) battery to assess neurocognitive performance. This computerized test battery consists of seven modules that include the follow: Simple Reaction Time 1 (SRT1), Simple Reaction Time 2 (SRT2), Math Processing (MTH), Match to Sample (MTS), Sleep Scale (SLP), Procedural Reaction Time (PRT), Code Substitution 9 (CS9), Memory Search 6 (MS6). Although the order by which the modules are presented to the participant remain constant, the stimuli in each of the modules is randomly presented in follow-up test sessions to limit practice effects.

Graded Symptom Checklist

The Graded Symptom Checklist (GSC) is a self-report symptom scale that assesses the presence of 18 concussion-related symptoms and severity using a seven-point Likert scale ranging from asymptomatic (0), to mild (1), to severe (6). During our baseline evaluation, participants were instructed to rate the severity of any symptom they reported feeling at least three times per week over the course of the summer preceding the baseline test session. During follow-up test sessions, the participants were asked to rate the severity of their symptoms based on what they felt at the time of testing.

Procedures

This was a double-blind, randomized study. The primary investigator was blinded from the test condition and the test results until the completion of the study. The participants were blinded from under which condition they were being tested. The primary investigator performed the testing for all preseason baseline screening and follow-up test sessions. One of the co-investigators (JPM) identified players to be tested after a given practice or game, but blinded the PI for which condition they were being tested. Once the season was complete, clinicians trained in the evaluation of the tests interpreted the results. Random test administration order occurred during this study to remove possible effects of testing order. The procedures used for the preseason baseline evaluation and those used for follow-up test sessions are detailed below.

Preseason Baseline Evaluation

Subjects were seated in a quiet room in order to perform the computerized neuropsychological testing using the ANAM battery. This testing procedure, consisting of seven modules, took about 20 minutes to complete. Balance performance was measured using the Sensory Organization Test (SOT). Directions were verbally recited to the athlete by the examiner prior to the start of test administration. The participant was asked to stand as motionless as possible in normal stance for each trial with feet shoulder width apart. Testing lasted approximately 10 minutes. A Graded Symptom Checklist was also completed by the athlete in which he reported and rated any symptom he experienced at the time of test administration.

Post Impact Evaluation

Post impact sessions began two weeks after the start of preseason camp and continued until the completion of the fall season and resumed in the spring season to reach the desired number of subjects. As stated earlier, athletes were identified by the co-investigator (JPM) based on the impacts they had sustained during a given practice or game. The co-investigator targeted athletes that met one of the following criteria: they had sustained at least one impact greater than 100 g, or they had sustained no impacts greater than 70 g. Testing session order was randomized among the population. Testing procedures performed during the preseason baseline screening were repeated within 24 hours of the end of the given practice or game.

The athletes were instructed to place their GSC into an envelope in order to blind the investigators from this information. Each test session lasted approximately 40 minutes to complete and, once again, the order in which the participant completed the various tests was randomized. Once an athlete had been tested under one condition, they were not targeted for the other condition for a period no less than two weeks.

Data Reduction and Analysis

Outcome measures obtained from the SOT included an overall balance composite, as well as ratio scores related to somatosensory, visual, and vestibular performance. Each outcome measure was taken from the computer printout. The ANAM yielded throughput scores for each of the individual test modules which were taken from the database on the computer. The GSC was analyzed for both the total symptom score and the number of symptoms reported. The total symptom score was obtained by summing all the individual symptom scores in the GSC and the number of symptoms was obtained as well.

In order to answer our first research question, we performed a within-subject repeated measures analysis of covariance (ANCOVA) on each outcome measure while covarying for the number of impacts greater than 70 g the participant had sustained since the beginning of the season and within the seven days leading up to the session in which they sustained an impact greater than 100 g. Other repeated measures ANCOVA, while controlling for the same two covariates, were performed on our outcome measures in order to assess the second research question. An alpha level of .05 was set prior to analysis and data was analyzed using SPSS for Windows Version 13.0 (SPPS, Inc.; Chicago, IL).

RESULTS

A total of 43 Division I collegiate football players completed the baseline and at least one follow-up test session: 24 participants completed the high testing condition and 36 participants completed the low testing condition. Twenty-two participants were able to complete both testing conditions. The results we observed for measures of balance performance, neurocognitive function, and symptomatology are detailed below.

Balance Performance

Results from our balance performance assessment are provided in Table 4. In assessing our first research question, we did not find any statistically significant differences in balance performance scores following an impact of 100 g. This was true for all our outcome measures, including an overall composite score ($F_{(1, 24)}$=.015, p=.905), somatosensory ($F_{(1, 24)}$=.065 p=.801), vestibular ($F_{(1,24)}$=.126, p=.727), and visual ($F_{(1,24)}$ = .101, p=.754) ratios. For our second research question, a statistically significant increase was observed for the vestibular ratio ($F_{(1,36)}$=8.677, p=.006) and the composite ratio ($F_{(1, 36)}$=12.754, p=.001). There were no observable differences in the overall, somatosensory ($F_{(1,36)}$=1 p=.325), and visual ($F_{(1, 36)}$ = 4.052, p=.052) ratios.

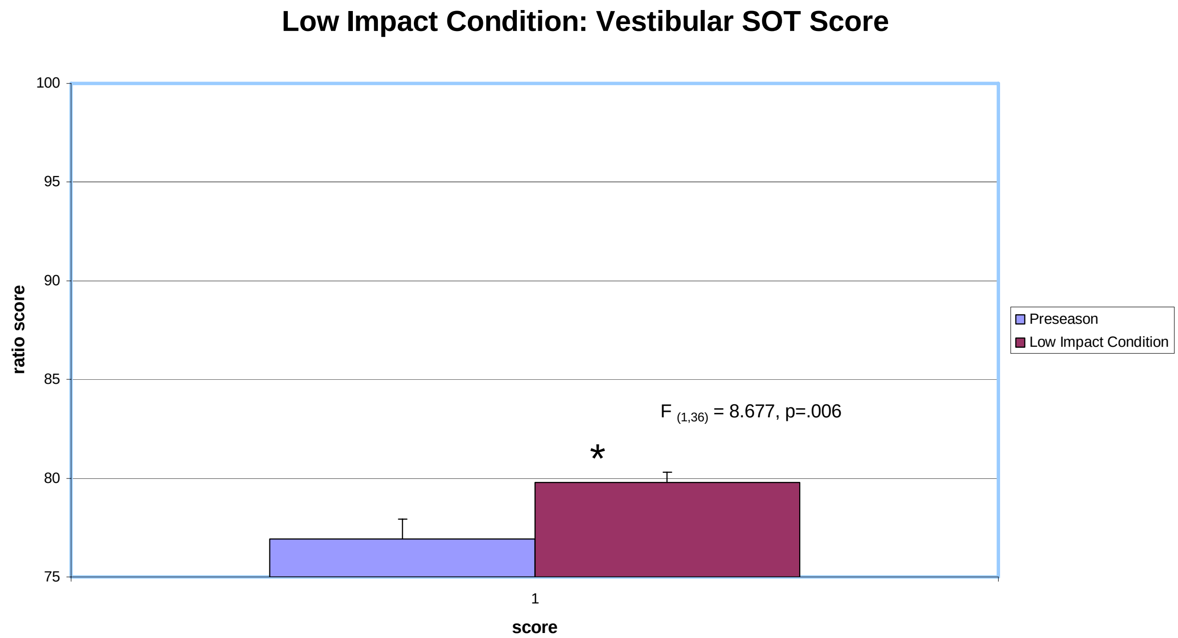

Figure 1. Low Impact Vestibular SOT scores vs. Pre-season baseline.

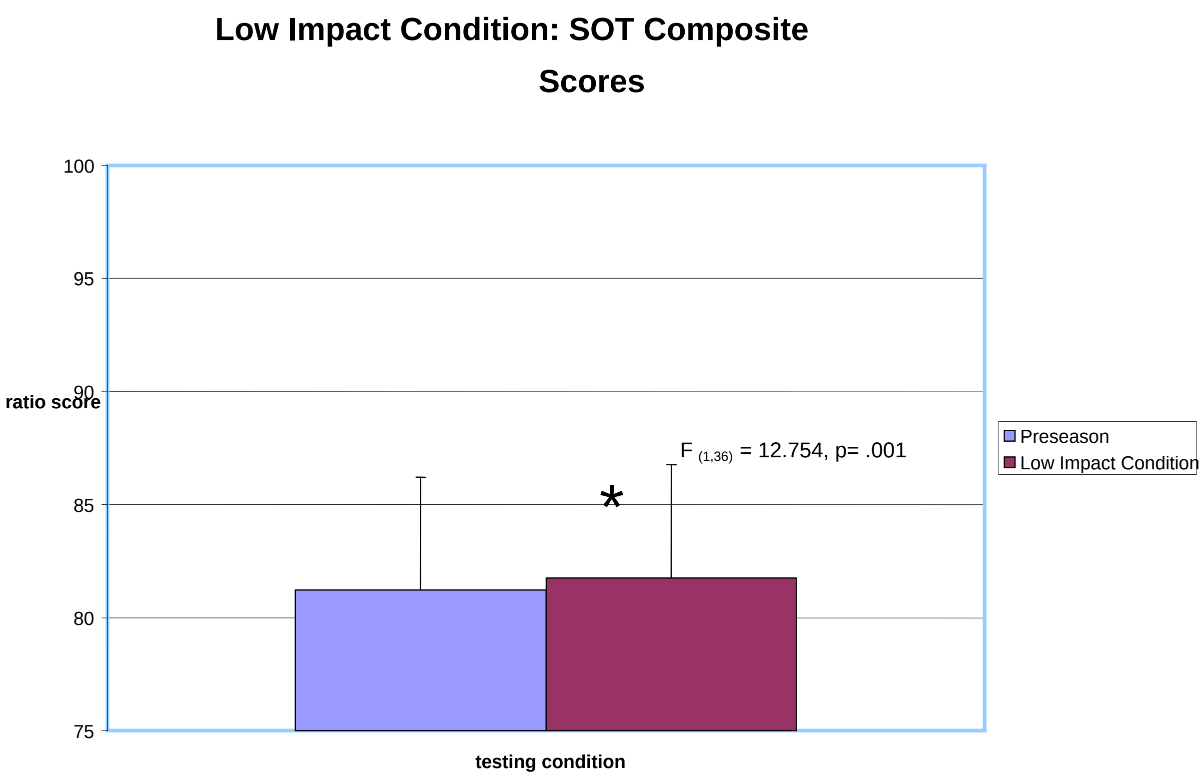

Figure 2. Low Impact Condition SOT Composite Scores versus Pre-season baseline.

Neurocognitive Performance

Following an impact greater than 100 g, we observed a statistically significant difference from baseline in the MTH module of ANAM ($F_{1,24}$=17.04, p<.001) (Figure 1). In response to our first research question, there were no other observable differences in the ANAM modules: SRT1 ($F_{(1, 24)}$=.492, p=.491), SRT2 ($F_{(1, 24)}$=.009, p=.927), MSP ($F_{1, 24}$=.498, p=.488), PRT ($F_{(1, 24)}$=1.43 p=.245), CS9 ($F_{(1, 24)}$=.027, p=.87), and MS6 ($F_{(1, 24)}$=.087, p=.771). Following a session where a head impact no greater than 70 g was sustained, statistically significant differences in the MTH ($F_{1,36}$=10.584, p=.003), SRT1 ($F_{(1, 36)}$=6.012, p=.02), CS9 ($F_{(1, 36)}$=4.836, p=.035), and MS6 ($F_{(1, 36)}$=5.402, p=.026) modules of ANAM were observed. No observable differences, in response to our second research question, were observed for the SRT2 ($F_{(1, 36)}$=.943, p=.338), MSP ($F_{1, 36}$=2.129, p=.154), and PRT ($F_{(1, 36)}$=.758 p=.39) modules of ANAM. Finally, there were no differences observed with the low condition comparison SS ($F_{(1, 36)}$= 3.77, p=.061), a subjective measure of cognitive fatigue assessed at the end of the ANAM testing protocol.

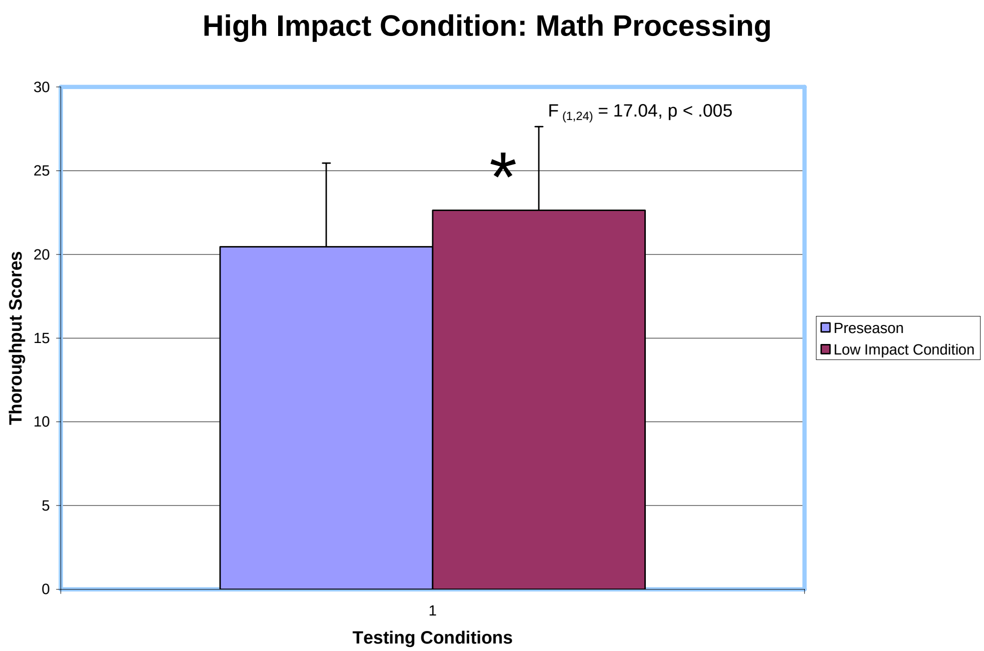

Figure 3. High impact condition math processing module scores versus preseason baseline.

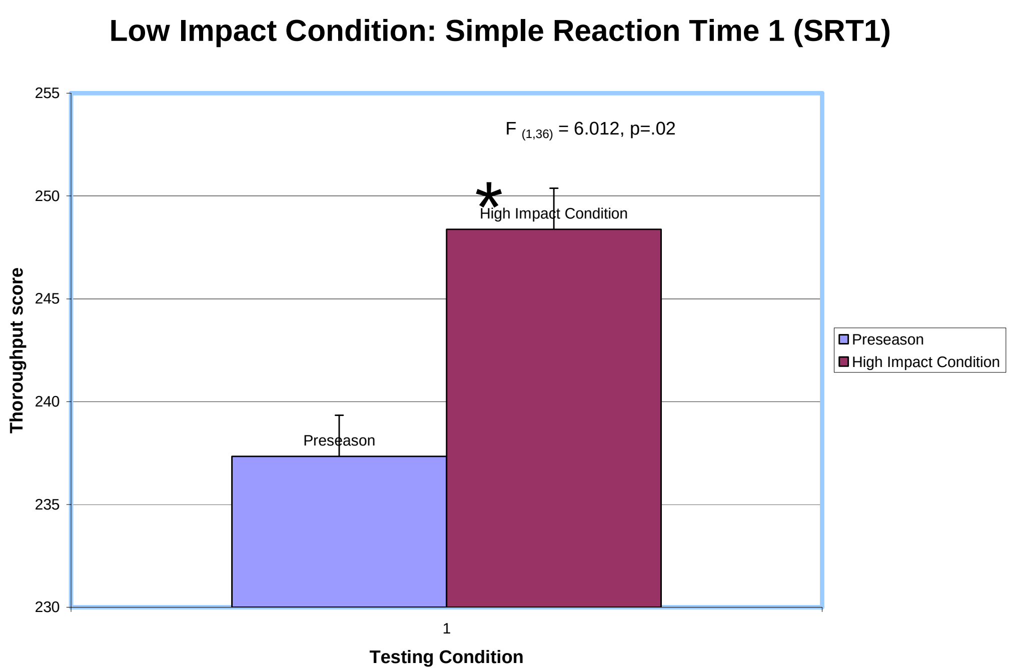

Figure 4. Low impact condition simple reaction time module versus preseason baseline.

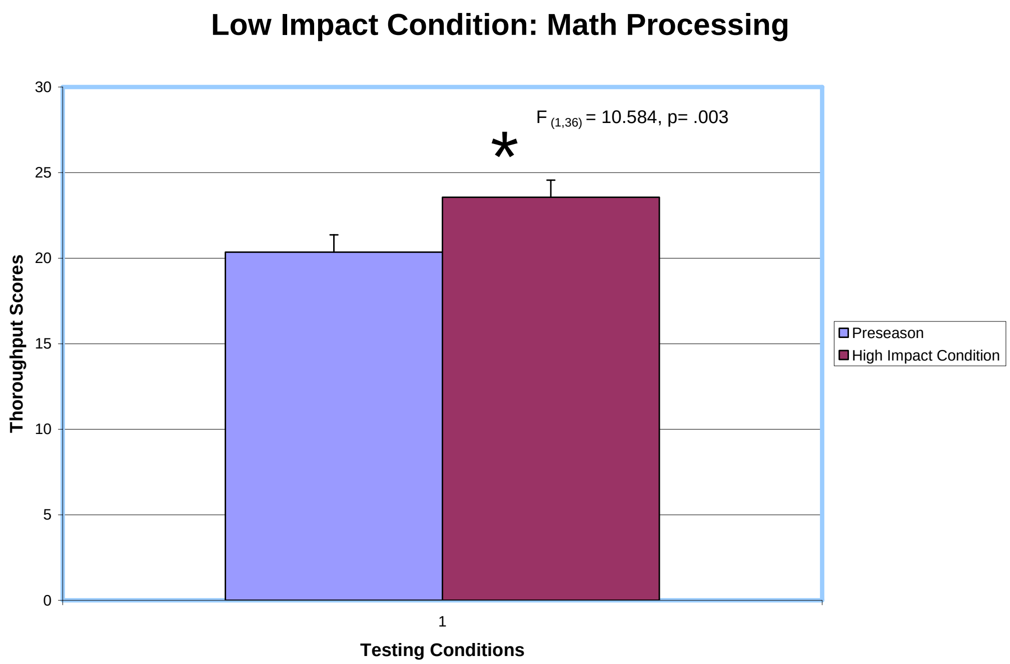

Figure 5. Low impact condition math processing module versus preseason baseline.

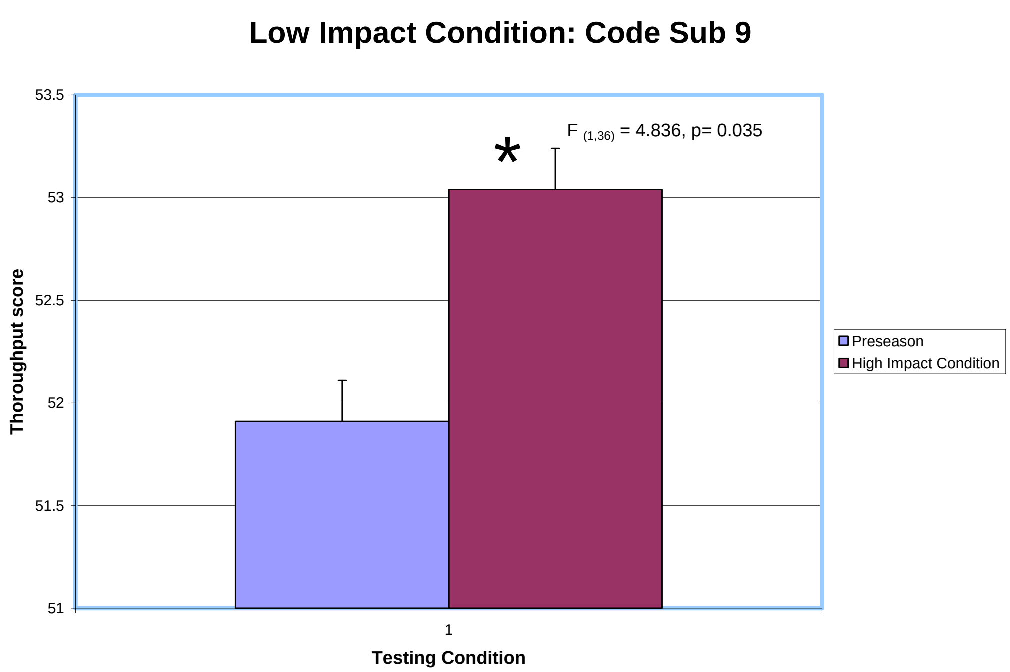

Figure 6. Low impact condition code substitution 9 module versus preseason baseline.

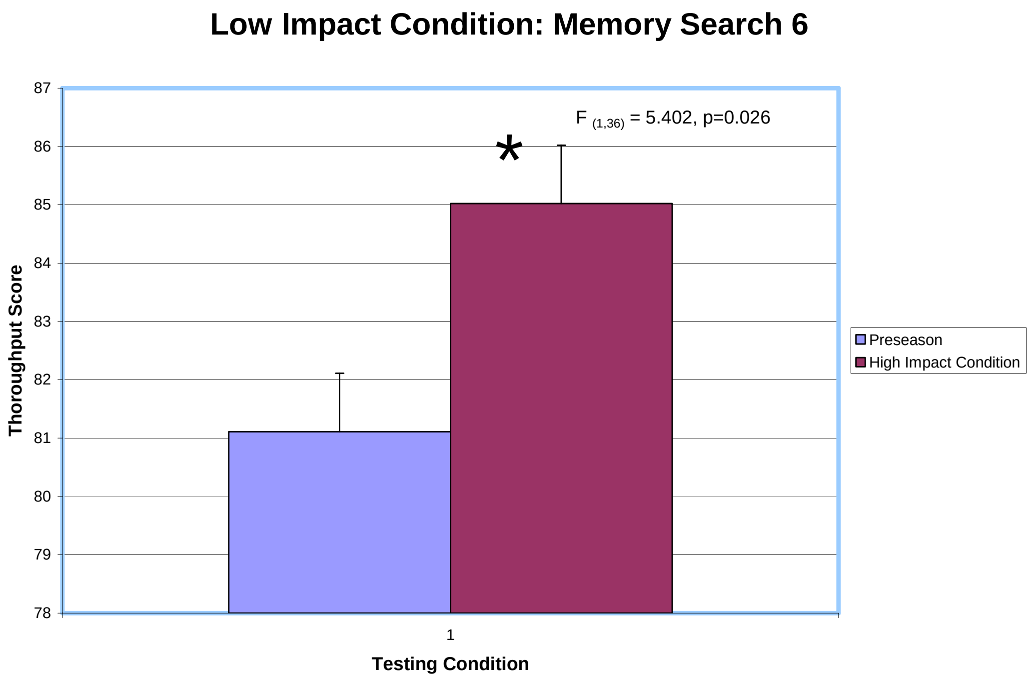

Figure 7. Low impact memory search module versus preseason baseline.

Symptomatology

Two subcomponents of the graded symptom checklist were analyzed, the total number of symptoms reported ($F_{(1, 24)}$ =3.540, p=.075), ($F_{(1, 36)}$ =1.4, p=.245) and the total severity of symptoms reported ($F_{(1, 24)}$ =.209, p=.652), ($F_{(1, 36)}$ =.001, p=.977) (Figure 10). The data analysis revealed the scores were relatively similar among the testing conditions and there were no statistically significant differences present.

DISCUSSION

The purpose of this study was to examine the effects of impact magnitude on the immediate performance of balance, neuropsychological functioning and symptomatology despite the clinical diagnosis of MTBI. This study was the first to collect real time data on collegiate football players and compare clinical outcome measures between high and low impact conditions. Finding the exact mechanism of this injury is needed in order to address prophylactic measures. A number of studies have investigated various biomechanical aspects of concussions in football; however, the majority of these studies have been in a laboratory setting using hybrid dummies. Some authors (Pellman, Zhang) have proposed an injury threshold, but these thresholds have not been confirmed through controlled studies. The first study to investigate real-time impacts in collegiate football players was conducted using fewer subjects than used for this study. Duma et al. reported an average linear acceleration of 32 ± 25 g that did not result in concussion in 38 players, whereas Pellman reported an average impact acceleration of 60 ± 24g in non-injured football players. Mihalik et al documented from data collected from the fall 2005 football season using the HIT System, players on average received impacts to the head around 19.46 ± 2.29g. He reported a maximum average impact of 199.98g with the highest impacts typically being recorded during practices.(Mihalik 2005) This information combined with the findings from this study perpetuates the need for a better understanding of impact biomechanics during participation in football. Various magnitudes have been reported in the literature to cause concussive injuries. Pellman et al has reported that a suspected injury threshold of 75-90g's to the head. Duma reported 25 impacts greater than 98 g, none of whom had a concussion, further questioning the speculated threshold but the issue of underreporting was mentioned as a possible explanation of those findings. Pellman et al. have investigated the biomechanics of improved helmet structures, biomechanics of the striking player and the results of concussion. These studies have been conducted in the laboratory and have limited field relevance. (Pellman 2003; Pellman, Viano et al. 2003; Pellman, Viano et al. 2003; Pellman, Lovell et al. 2004; Pellman, Powell et al. 2004; Pellman, Viano et al. 2004; Pellman, Viano et al. 2004; Newman, Beusenberg et al. 2005; Pellman, Viano et al. 2005)

This study was conducted in an attempt to determine the efficacy of using helmet telemetry to identify concussion and/or concussion-like signs and symptoms in the absence of subjective information provided by the athlete. The results of this study revealed no major differences between baseline and either of the two impact magnitude conditions, thus refuting our research hypotheses. In addition this study also raises questions about the validity and clinical significance of those studies conducted by Pellman, Zhang, and Newman. Questions about a much higher injury threshold are raised, as are the role other factors in an impact to the head might play to causing a MTBI, are raised.

A study conducted at Wayne State investigated an injury threshold and found that rotational and translational acceleration were the most important factors in the severity of the presence of a MTBI. The study although not using real life subjects, rather brain models created with synthetic materials replicated to be just like a cadaver brain and skull, was able to look at the effects impacts had to the brain itself, not just the skull. The basis of the threshold is gathered from a study done in the laboratory, using game film to recreate the impacts and on models that are not exact to the players head in the video. The threshold was examined from a physiological perspective versus this study done which examined real field situations and effects on test measures of balance and neuropsychological functioning. It may be that the theoretical threshold speculated by Zhang et al. has effects and causes changes in the structure of the brain microscopically but does not effect the gross motor skills tested in the various MTBI batteries. Perhaps the single measure of linear acceleration was not enough of a predictor, or a different predictor than the rotational and translational acceleration mentioned in the Wayne State study. The linear acceleration associated with the combination of the rotational and translational may be significantly higher as proven by this study. The suspected threshold of 98 g should be reevaluated and if the injury threshold is in fact much higher, than there would be no decline in the scores we gathered for balance, neuropsychological and symptomatology at the current level.

SOT Measures

Balance was not largely affected by the magnitude of the impact to the head. The low impact condition actually resulted in an increase in balance performance (composite and vestibular) when compared to baseline scores. The visual component of the SOT in the low impact condition was approaching significance, thus marking an increase in balance performance. However when looking at the outcome measures, the effect sizes are so small that the difference is negligible from a clinical perspective. This study investigated players that did not self-report symptoms to the certified athletic trainer and were not clinically diagnosed with a concussion. The majority of published studies have reported that balance performance is affected in athletes diagnosed with concussion.[20] & [21] The increase in balance scores in the pool of participants that took part in the study could be for a number of reasons. These participants were not clinically diagnosed with a MTBI; therefore changes should not be expected to be seen. The sheer magnitude of the impact the players took was not of a value that it affected the various components of the vestibular and somatosensory system. The studies conducted by Pellman, Zhang and Newman did not look at test measures as a result of the impact rather took those that were diagnosed with a MTBI and recreated the impact.

If the low impact testing condition resulted in significant improvements in balance performance, as a clinician, one should question the lack of improvement in the high impact condition. Since random testing order occurred, it negates the effects of learning. If it is natural to have an improvement on balance performance as the duration of training continues, then a lack of one with the high impact condition might indicate a clinical significance to the medical professional. A study conducted by Mrazik et al. looked at the effects of severity of injury on various parametric measures and found some variation in balance testing. There were no significant trends seen in the various sub-components of the SOT measures. All tests were taken at least 24hrs. post injury whereas our study performed the testing within the first 24 hrs. of the session in which he sustained the impact. This same study found that the player who sustained a grade I concussion had virtually no deviation from baseline measures, thus confirming that the magnitude of the impact may not be the sole determinant of a MTBI.

Neuropsychological Measures

Significant differences were observed between baseline and the low testing condition on the ANAM battery. The most obvious decline in performance was observed for both the Simple reaction time-1 and Code substitution subtests, suggesting that reaction time and delayed memory are negatively affected following the day in which the players experienced no impacts greater than 70 g. Improvements in performance observed in Procedural reaction time, and Memory search-6 are difficult to explain. The inconsistencies among the change in scores could have been a result of any number of unforeseen and uncontrollable variables. For example, similar to the SOT outcome measures, the effect size is small leading us to find little clinical significance. The study conducted by Mrazik et al. as mentioned above found that the individual who was diagnosed with a grade I concussion actually had an improvement from baseline scores on the first post-injury evaluation, and the overall test results showed virtually no impact of the MTBI on his performance in the various tests. In the other two cases of MTBI, even the more severe cases, the athlete surpassed the baseline measures on that particular individual. This information suggests that balance performance cannot be the only factor the clinician uses to determine return to play. Peterson et al. also concluded that comparing just the means of the various tests between the two groups, it emphasizes that return to baseline is the best indicator of return to play decisions.

In addition, it has been reported in the literature that learning effects are found with repeated use of the ANAM battery that cause perhaps a false sense of improvement in scores on the ANAM.(Levinson and Reeves 1997) The study conducted by Levinson and Reeves had the subjects retaking the test every two to three months as opposed to the typical serial testing that occurs in sports medicine. Practice effects are a valid limitation of neuropsychological tests. The amount of practice effect that has been incurred depends on the nature of the test, the time period of testing, and how many times the subject is tested.(Echemendia and Julian 2001; Grindel, Lovell et al. 2001) Practice effects can alter the course of action that the athlete should be receiving. An athlete has the potential to improve the scores from the baseline battery due to these practice effects. Most research has also shown that these practice effects are null and void after a period of two weeks but in some cases may last upwards of seven weeks. This study mandated a two week ‘buffer period' to allow at least two weeks in between test session one and test session two. This two week period was an effort to eliminate the practice effects experienced with ANAM.

In addition to the learning effect between each session, it was later found out that the incoming freshmen were given a similar battery to test for learning disabilities by the academic center. This administration of a test of this nature further perpetuates the learning effect. Other test results have been shown to discern the minute deficits in neurocognitive functioning that occurs with concussion.(Lovell 2002) Different types and severity of concussions have been documented to have different results in symptom reporting and neuropsychological testing. Echemendia et al. discussed the differences in concussions and how some do not disturb those parts of the brain that affect the results of neuropsychological tests. Instead, the athlete may have deficits else where or be extremely symptomatic. He also states that neuropsychological testing is not as sensitive as clinicians typically need it to be, although still represents the best tool athletic trainers have to assess deficits following concussion.(Echemendia and Julian 2001)

Another confounding variable to consider when interpreting improvements on the ANAM scores should be the effects of attention deficit disorder (ADD), a learning disorder which was prevalent in a significant percentage of our football team has been diagnosed with. The variability of this learning disorder and how the outcome measures of ANAM are altered has historically been avoided. The effects of this disorder may help explain why there was in fact an improvement. Often athletes are medicated for ADD and typically only take their medicine to focus on academics. During the summer a majority of athletes do not take their medication since most are taking a reduced class load, if any. Baseline measures are taken during the summer, generally during that time period that the athlete is not taking the prescribed medication. Thus, when the athlete retakes the test during the season, the athlete is medicated and as a result, is able to better focus. However, this gray area is one that warrents further study so that we might better understand the full repercussions of ADD on neuropsychological tests.

Other test results have been shown to discern the minute deficits in neurocognitive functioning that occurs with concussion. (Lovell 2002) Different types and severity of concussions have been documented to have different results in symptom reporting and neuropsychological testing. Echemendia et al. discussed the differences in concussions and how some do not disturb those parts of the brain that affect the results of neuropsychological tests. (Echemendia, Putukian et al. 2001) Instead, the athlete may have deficits else where or be extremely symptomatic. They also state that neuropsychological testing is not as sensitive as clinicians typically need it to be, although still represents the best tool athletic trainers have to assess deficits following concussion. (Echemendia and Julian 2001)

GSC measures

The main purpose of this study was to see if there were deficits in balance and neuropsychological function in the absence of self reported symptoms. Underreporting is a global problem when dealing with MTBI and looking at other ways to identify people who have suffered from an MTBI without their self report was of great interest to the primary investigator. Our analyses had no significant differences between the two testing conditions and baseline with symptom reporting or severity of symptoms reported. These players had received a significantly high magnitude impact to the head and even within 24 hours they were still symptom free relative to pre-season baseline measures. It has been long thought that a hard hit to the head would result in a concussion however; this study proves that the magnitude is not the only factor in predicting a concussion. As clinicians we often rely on the athlete to be honest with us when dealing with a concussion and our results support the notion that if an athlete is symptomatic he or she will be unable to do the activity without having those symptoms interfere. Therefore, there is something to be said about the symptom reporting by the athlete.

It has been stated in literature that self-reported symptoms should never be the sole determinant of a concussion. Underreporting by the athletes is a problem that plagues the prevention of the detrimental effects suffered by a concussion. As stated earlier, football players compete in a demanding and intensely physical environment where many players have little knowledge about the physiological reaction as a result of impacts to the head, the concussive cascade, and their disposition later in life as a result of repeated impacts to the head.(Kaut, DePompei et al. 2003) Underreporting is a large and prominent issue in dealing with concussions.(Lovell and Collins 1998; Echemendia and Julian 2001; Collins and Hawn 2002; Field, Collins et al. 2003; Kaut, DePompei et al. 2003) The nature and environment of the sport breed the growing problem of underreporting.

Football players have become accustom to symptoms that are commonly associated with concussions. Athletes learn to expect these symptoms from the nature of their sport and do not think it is abnormal. Many of the athletes had difficulty distinguishing what symptoms were appropriate to put down because they did not feel it was due to the impact sustained, rather the norm of what they feel at the end of a hard practice. One study documented ½ participants did not understand the correlation of symptoms to a head injury.(Kaut, DePompei et al. 2003) A study done conducted by Macciocchi found the most common symptoms reported in concussed individuals were headache, dizziness, and memory problems.(Macciocchi, Barth et al. 1996) A study conducted by Kaut et al. found that 30% of athletes reported receiving a direct blow to the head that resulted in dizziness, proving to be the highest frequency of symptoms reported by football players (35%). A study conducted by Erlanger et al reported 12 % of subject pool would not have been identified as having a concussion if based solely on self-reported symptoms. He sampled a group of concussed athletes that underwent CRI evaluation and the scores revealed deficits in cognitive functioning among all the subjects.(Erlanger, Saliba et al. 2001)

Symptoms have been shown to resolve before balance and neurocognitive functioning had returned to normal.(Collins, Grindel et al. 1999; Echemendia, Putukian et al. 2001; Field, Collins et al. 2003) Another study found that high school and collegiate football players reported fewer symptoms five to seven days post concussive injury than they reported on their baseline measures. (Field, Collins et al. 2003) The ability of the program to determine the various components of the impact such as time, location, duration, magnitude and history of hits to the head is important because in the future that particular information may be a key criteria needed to identify those players that may have suffered a concussion. Football historically has been known to view loss of play due to a concussion as a sign of weakness. With this mentality, many inherent risks are present in this sport and with the largest number of participants in the world; many injuries are treated each year.

Future Direction

With the vast technology that has and continues to be created, much more field data will be acquired. With this data, researchers can learn more about the specific biomechanics of impacts in football to the head. Analysis of impact location, number of impacts, previous history, and position may play a significant part in determining the threshold magnitude of a concussion. With more information about impacts to the head, strides will be hopefully be made in the prevention & return to play of concussion. Research must determine a way to perfect early recognition of those players susceptible to concussive injuries. Once the recognition, preventative component has been determined then research about return to play can be engaged. Improvements in helmet design and tackling techniques need to be addressed once the research provides the data to support the efforts. Education and getting the players involved is vital to further research in this area. Throughout the course of this study players had little interest or desire to take part in a study that would benefit them based on their participation. Football players underreport concussions because of the seriousness with which the medical staff appoints to them, however, the players make no effort to learn how to avoid getting a concussion in the first place. The more research that is done in the field on actual football players versus those tests done in the laboratory, the more athletic trainers can educate their athletes.

Limitations

Due to time conflicts, subject compliance and injuries suffered throughout the season, not all 43 players that were baselined were able to complete both test conditions. Throughout the data analysis many measures were approaching significance but perhaps due to the small sample size, that significance was not reached.

The 16-24 hour window in which the players were tested was possibly not early enough to identify deficits that would have been present immediately after the impact. However, as previously stated, underreporting is extremely frequent in football thus; a majority of players would not have reported their symptoms to the ATC until the next day. Due to the desire to replicate a realistic situation in the field, the time window in which the testing was done in was clinically practical. At the University of North Carolina- Chapel Hill, the normal protocol for testing concussed athletes is to wait till they are at least asymptomatic. The earliest that would typically occur is 16- 24 hours of the impact.

Much is unknown about many components of concussions and the concept of an injury threshold existing is speculation. The results from this study raise more questions as to what other important components must be analyzed to see how the "pieces of the puzzle" in the mechanism of injury for a concussion fits together.

Clinical Significance

This study has resulted in new and important information regarding the most predictive factor of an impact that results in a MTBI. This was the first field study to really examine the theoretical concussive injury threshold in actual live subjects in real-time situations on various concussion testing protocol. Surprisingly, there were little to no acute deficits seen after an impact greater than a 100 g to the head and improvements seen in testing parameters with impacts below 70 g. The results on the neuropsychological battery support the statement that there need not be a deficit in scores from baseline to indicate a MTBI, rather an absence or reduction of learning effects can be just as conclusive that the subject has a concussion. The finding on the symptomatology emphasizes the importance of the athletes' self-reported symptoms. If the athlete receives a high magnitude impact and does not have any symptoms associated with a concussion, then we are less likely to assume that he or she has in fact suffered a concussion. The clinician should make an effort to inquire about symptoms with an athlete who has taken a 'hard hit' not just immediately but within 24 hours of the impact. The findings with the balance scores support evidence in the literature that the vestibular and visual components of balance are the most sensitive to head trauma and will be the first to show changes in score. As clinicians, if a MTBI is suspected and sophisticated technology is unavailable than giving the athlete a task that challenges the visual and vestibular components of balance should aid in the assessment of MTBI.

Anecdotally, there have been several cases in which players have been diagnosed with concussion after a moderate impact magnitude (approximately 60-70 g). Three players in particular have received impacts below the 98 g threshold. These particular cases illustrate that the theoretical concussive injury threshold is not the sole predictor of injury as previously speculated and many other factors may play a role in the effect of the magnitude impact on causing a concussive injury.

Contrary, we have had numerous players receive a plethora of impacts with a magnitude greater than 100 g that have had no clinical symptoms of a MTBI. This study highlighted the clinical evidence that there were no statistically significant decreases in the various outcome measures that is used to help solidify the diagnosis of a MTBI. Bleiberg concurs with Collins that cognitive deficits as a result of a MTBI not always need to be in the form of a decrease in scores when compared to baseline scores but rather an absence or reduction of practice effects in the various outcome measures. (Bleiberg, Cernich et al. 2004) This study does support the notion that a lack of practice effects may signify a deficit due to the impact magnitude. However, having said that and looking back at the anecdotally evidence, magnitude may not be the sole predictor of the mechanism of concussions.

Examining the frequency of impacts that had a magnitude greater than 100 g, one can conclude it is very diminutive. The majority of the impacts sustained by the football players in this study were well concentrated in the lower ranges of impact magnitudes. Nearly ninety percent of the impact magnitudes recorded over the time period of the study ranged from 10 g- 70 g. This range should alert the certified athletic trainer that a majority of the impacts players receive are not of the higher accelerations (>80-100 g) believed to cause concussion.

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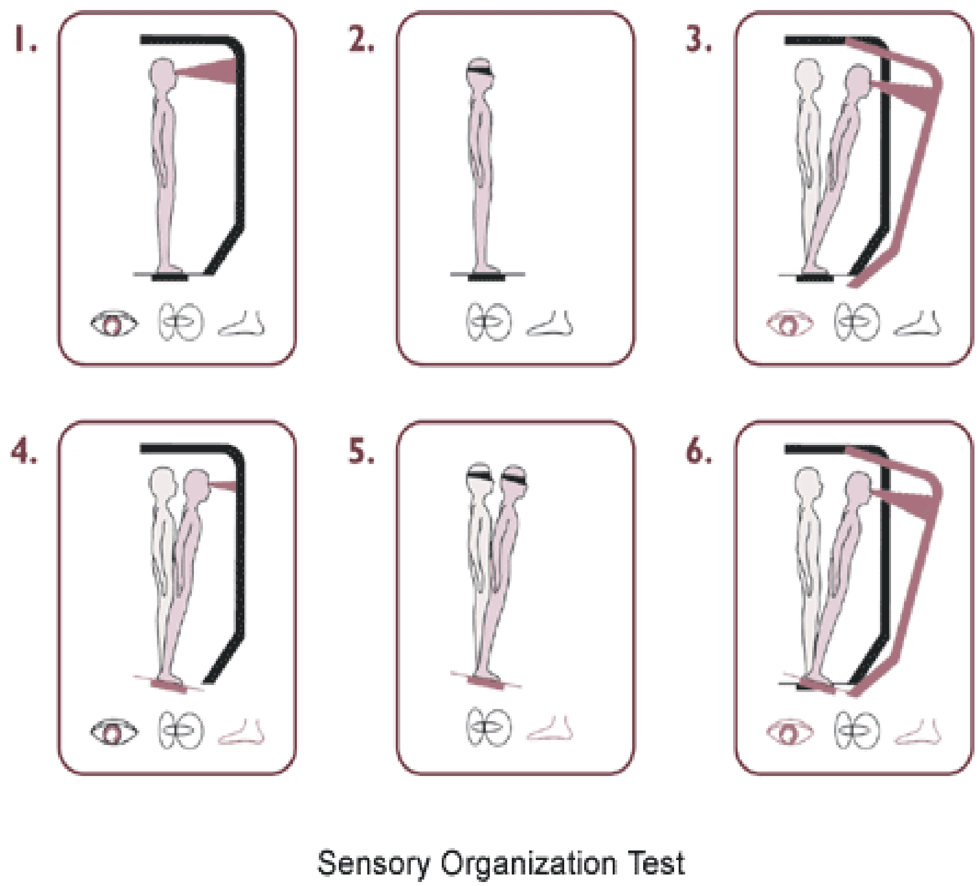

Figure 8. Sensory Organization Test conditions**.**

Table1. Means (±SD) compared between pre-season baseline and high impact testing condition (n=24)

Outcome Measure	Baseline	High-Impact	F	p-value	Effect Size
Simple reaction time-1	237.34 ± 35.93	248.38 ± 29.89	0.492	0.491	0.31
Simple reaction time-2	230.76±46.38	229.94±50.61	0.009	0.927	0.017
Math processing*	20.58±5.99	23.56±7.24	17.04	0.001*	0.5
Matching to sample	40.3135±13.99	43.56±14.49	0.498	0.488	0.23
Sleep Scale*	3.0417±1.55	3.79±1.69	6.52	0.019*	0.48
Procedural Reaction Time	84.85±17.66	99.77±28.35	1.43	0.245	0.84
Code Sub 9	51.91±11.21	53.40±7.77	0.027	0.87	0.13
Memory Search 6	81.11±13.60	85.02±17.83	0.087	0.771	0.29
Total # of symptoms reported	1.65±2.06	3.04±2.76	3.54	0.075	0.67
Total symptom score	4.04±5.96	5.22±5.89	0.209	0.652	0.2
Somatosensory	96.69±2.62	98.18±4.26	0.065	0.801	0.57
Visual	92.10±5.65	90.08±11.19	0.101	0.754	0.36
Vestibular	78.07±10.89	77.99±11.02	0.126	0.727	0.007
Composite	81.34±5.65	80.10±7.66	0.015	0.905	0.22

* Indicates significance at the .05 level

Table 2. Means (±SD) compared between pre-season baseline and low impact testing condition (n=24)

Outcome Measure	Baseline	Low-Impact	F	p-value	Effect Size
Simple Reaction Time 1*	238.89±33.57	252.92±28.27	6.012	0.020*	0.42
Simple Reaction Time 2	233.35±42.34	237.01±33.72	0.943	0.338	0.45
Math Processing*	20.45±6.11	22.63±6.61	10.584	0.003*	0.36
Match To Sample	40.49±13.39	47.85±13.21	2.129	0.154	0.55
Sleep Scale	2.97±1.66	3.06±1.41	3.77	0.061	0.05
Procedural Reaction Time	88.50±17.58	97.27±23.16	0.758	0.390	0.5
Code Sub 9*	51.65±11.40	55.38±9.59	4.836	0.035*	0.33
Memory Search 6*	79.10±16.95	89.72±19.11	5.402	0.026*	0.63
Total # symptoms reported	1.81±2.44	2.61±2.567	1.4	0.245	0.33
Total symptom score	3.92±6.583	4.03±4.582	0.001	0.977	0.02
Somatosensory	97.09±2.83	96.03±3.50	1	0.325	0.37
Visual	92.02±6.19	90.05±10.88	4.052	0.052	0.32
Vestibular*	76.92±11.52	79.80±8.82	8.677	0.006*	0.25
Composite*	81.21±5.45	81.76±7.22	12.754	0.001*	0.1

* Indicates significance at the .05 level.

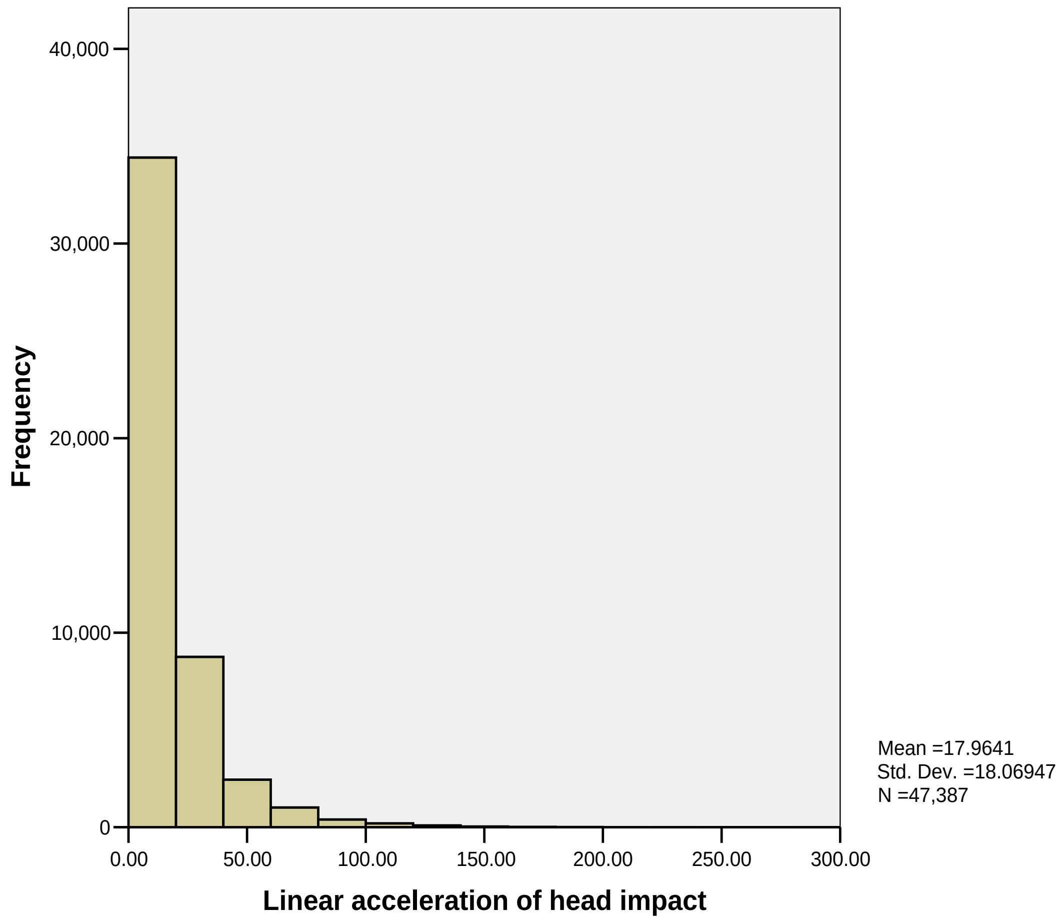

Figure 9. Frequency of impact magnitudes over the testing period.

LEGEND TO FIGURES

Figure 1: Low impact condition ratio scores versus preseason baseline ratio scores for vestibular component. * indicates significance at the .05 level.

Figure 2: Low impact condition ratio score versus preseason baseline ratio scores for composite component. * indicates significance at the .05 level.

Figure 3: High impact throughput score versus preseason baseline throughput scores for math processing on ANAM. * indicates significance at the .05 level.

Figure 4: Low impact throughput score versus preseason baseline throughput scores for simple reaction time 1 on ANAM. * indicates significance at the .05 level.

Figure 5: Low impact throughput scores versus preseason baseline throughput scores for math processing on ANAM. * indicates significance at the .05 level.

Figure 6: Low impact throughput scores versus preseason baseline throughput scores for code substitution on ANAM. * indicates significance at the .05 level.

Figure 7: Low impact throughput scores versus preseason baseline throughput scores for memory search 6. * indicates significance at the .05 level.

Figure 8: 6 conditions of the Sensory Organization Test (NeuroCom)

Figure 9: Frequency of impact magnitudes over testing period.