5-20-2005

The Relationship between Aerobic Fitness and Concussion Risk, Severity, and Recovery in High School Football

Robert James Elbin
University of New Orleans

THE RELATIONSHIP BETWEEN AEROBIC FITNESS AND CONCUSSION RISK, SEVERITY, AND RECOVERY IN HIGH SCHOOL FOOTBALL

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Arts
in
The Department of Human Performance and Health Promotion

by

Robert J. Elbin III

B.S. University of New Orleans 2002

May 2005

DEDICATION

To my family:

Mom, Dad, Kyle, Kurt, Danae, Grandma, and Pap

"I can do all things through Christ which strengthens me"
Philippians 4:13

ACKNOWLEDGMENTS

"When you come to a fork in the road, take it!"

-Yogi Berra

To Dr. Anthony Kontos. Thank you for mentoring me through my first research experience. I greatly appreciate your patience and confidence in me. You have inspired me to pursue a career in academics and to continue this crazy ride throughout a doctoral program. Hopefully we can find some time to do some mountain biking as well!

To Dr. Elisabeth Gleckler. You were the spark plug that kept me sane through this process. I have enjoyed our brief chats and thanks for believing me.

To Coach Waugerman. Eight years later those talks and sayings before practice finally all made sense. You were the coach that made me realize that baseball is truly a game of "life." It is only by my failures and successes as a former athlete that I have truly found what it means to do "whatever it takes." Thanks for everything.

To Coach Duke. Just another chapter in "The Book." Thanks for believing and telling it like it is. I appreciate your knowledge and advice on the decisions that have gotten me this far.

To Jimmy Ray. I appreciate all your knowledge and advice on my advancement into academe. Thanks for everything.

To Mom and Dad. I would like to think that I have made you proud by my achievements thus far. You both have shown me what it means to work hard for something, and the easy way is not always the best option. I love you both.

To Kurt, Kyle, and Danae. Even though I have been away from home I appreciate all your support through baseball and graduate school. Thanks, I am sure that I will have the chance to return the favor during your future endeavors. Love ya guys.

To Grandma and Pap. Where do I begin? You both have shown me what it is to have faith and to believe in something that you cannot see. It's true, problems in life don't seem as complicated when they are handled by grandparents. Thanks for so much, I love you both.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The purpose of this study was to examine the effects of aerobic fitness level on concussion risk, severity and recovery in high school football players. Participants (*N*=158) completed aerobic fitness (i.e., estimated VO_2 max) and baseline neurocognitive tests (i.e., ImPACT). Concussed athletes completed ImPACT every 24-72 hours until they were asymptomatic or returned to baseline levels. A post-season questionnaire assessed unreported concussions and symptoms. Twenty players incurred concussions. Previously concussed athletes were 3.71 times more likely to be concussed than those with no concussion history. Severely concussed participants reported lingering symptoms. Previously concussed athletes high in aerobic fitness reported fewer symptoms than those low in aerobic fitness. Non-significant trends suggested that aerobic fitness might be related to faster recovery times and fewer symptoms. Twenty-eight percent (*n*= 38) of non-concussed participants reported a potential concussion and symptoms that were not recorded by medical staff during the season.

CHAPTER I

INTRODUCTION

Statement of the Problem

Imagine two high school football players converging on an opponent to make a tackle. Both players successfully make the tackle, but in the process have incurred a significant impact to the head. As is typically the case in this situation, the two players continue playing, and disregard their injury as part of the game. However, after the game, one player experiences several symptoms including nausea and headache, and is having trouble recalling events prior to his injury. The symptoms displayed by this athlete indicate that he has sustained a mild concussion. The other player appears to be symptom free and reports no difficulty in remembering any events before or after the collision. The impact force sustained by each player was the same; however, they experienced different outcomes. Researchers know very little about which factors influence concussion risk, severity, or recovery in cases such as these.

A concussion is defined by the First International Conference on Concussion in Sport as "complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (p. 58) ;(Aubry, Cantu, Dvorak, Graf-Baumann, & Johnston, 2001). A concussion or mild traumatic brain injury (MTBI) is caused by a direct or indirect blow to the head resulting in symptoms (e.g., loss of consciousness, amnesia, dizziness, confusion, fogginess, and headache) and neurocognitive decrements. Researchers have linked the severity of concussion to the number of symptoms presented and neurocognitive decrements in injured athletes (Field, Collins, Lovell, & Maroon, 2003). Understanding the effects of a mild concussion can help trainers, coaches, and parents make better decisions in the recovery of the athlete. Allowing athletes to return to competition too soon could subject them to cumulative effects of this injury such as long term neurocognitive decrements and increased risk for additional and more severe concussions (Iverson, Gaetz, Lovell, & Collins, 2004).

Another factor that has been examined by researchers is concussion history. Athletes who have sustained a previous concussion of any severity have an increased risk of subsequent concussions (Zemper, 2003). Research also (Zemper, 2003) suggests that three or more concussions can lead to long term decrements and symptoms, and increased risk for severe concussions. Multiple concussions may also predispose an athlete to a more severe head injury as a result of second-impact syndrome (Iverson et al., 2004). Consequently, information regarding concussion history is now included on most physical forms and medical questionnaires in order to identify athletes who are at risk for concussion and to disqualify individuals who sustain too many concussions in a short period of time. In fact, the Louisiana High School Athletic Association mandates that any athlete who sustains three concussions in one season must be terminated from all athletic competition for the remainder of the season and/or academic year.

Symptoms and concussion history also form the basis for determining severity and recovery from concussion (Zemper, 2003). Surprisingly though, there is limited research regarding possible factors which may influence concussion recovery time. Studies have consistently demonstrated that concussed athletes experience different recovery times, but have failed to examine which factors contribute to recovery (Lovell & Collins, 1998).

One potential factor that might influence concussion recovery is aerobic fitness. Aerobic fitness significantly improves neuropsychological performance in older individuals with neurocognitive decrements (Dustman, Ruhling, Russell, Shearer, & Bonekat, 1984). However, these decrements and symptoms as reported in Dustman et al. (1984) are similar to the symptoms reported by mildly concussed football players by Collins, Iverson, Lovell, McKeag and Norwig (2003). Therefore, the level of aerobic fitness may serve as a predictor of concussion risk, severity and recovery via its effects on the brain and subsequent neurocognitive performance.

Nature of the Problem

There are an estimated 43,000 concussions annually in high school football (Zemper, 2003). The concussion incidence rate for football is 3.71 concussions per 100 high school players, which is much higher than any other American high school sport. These numbers suggest that developing a better understanding of concussion and the factors that affect it among high school athletes is warranted. Fifty-seven percent of all concussions in high school football are caused by helmet-to-helmet contact (Zemper, 2003). Players have a tendency to use their helmet as a "battering ram" (i.e., spearing) while making tackles. The resulting impact causes the skull's forward momentum to stop abruptly, while the brain lags behind. This "rocking" action of the brain causes the shearing or tearing away of tissue against the bony protuberances of the skull, resulting in broken blood vessels and capillaries. This hampers circulation of blood throughout the brain, and in turn, decreases the amount of glucose supplied to the brain. The brain needs glucose in order to recover from injury, but does not receive the required amount following a concussion (Bailes & Cantu, 2001). The effects of this "neurological cascade," as it is commonly referred to, result in a depressed state of cognitive functioning and symptoms which can last up to ten days (Collins, Grindel, Lovell, Dede, & Moser et al., 1999).

As mentioned earlier, during and after a concussion, certain symptoms are present in the injured athlete. Traditionally, the benchmark symptoms of concussion severity were loss of consciousness (LOC) and posttraumatic amnesia (PTA) (Lovell, Iverson, Collins, McKeag, & Maroon, 1999). A concussion that involves these two symptoms is classified as the most severe; and all other symptoms warrant a mild grade of concussion. Recent studies have questioned the validity of LOC and PTA in determining concussion severity (Lovell, Collins, Iverson, Field, & Maroon et al., 1999). One such study examined the symptoms of 1003 reported and diagnosed concussions (Guskiewicz, Weaver, Padua, & Garrett, 2000). The majority of symptoms presented in these injuries did not involve either LOC or PTA. This suggests that other symptoms (headache, nausea, dizziness, etc…) which accompany a mild concussion are more prevalent than previously thought. Consequently, this finding has generated more interest in the duration of these "mild" symptoms, and their relationship to concussion severity and recovery.

Mild concussions involve "hidden" or subtle symptoms such as a headache, dizziness, brief disorientation, and/or nausea (Lovell et al., 2003). These symptoms are difficult to assess as they are only identified by self-report from the injured athlete. Therefore, in many cases, medical personnel have no way of knowing if an athlete has sustained a mild concussion unless it is self-reported. Studies have suggested that education programs are needed to inform athletes, parents, coaches and medical staffs of the signs and symptoms of mild concussion and potential risks of unreported injuries (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004).

Measuring symptoms to predict concussion severity poses another problem for the sports medicine team. Team physicians and athletic trainers typically follow anecdotally-based guidelines to assess concussion severity. Concussion guidelines are numerous, inconsistent and arbitrary in nature. In fact, there are currently over 30 different guidelines in use. Although many medical organizations and professionals have devised and endorsed guidelines for assessing on-field concussion symptoms, there is no agreement on which one is best (Collins, Stump, & Lovell, 2004). In a study by Lovell et al. (1999), return-to-play guidelines were a poor predictor of concussion severity. Most guidelines base their assessment of concussion severity around LOC. Loss of consciousness is an important predictor of concussion severity, but as Lovell et al. (1999) reported, it does not predict neuropsychological impairments in concussed athletes.

In summary, clinical on-field guidelines have fallen short of identifying the lasting effects of a concussion beyond the initial time of injury. Other tests such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) scans have proven helpful in identifying severe concussions, which involve cerebral swelling and edema. However, these tests are not suited for examining the more subtle cognitive deficits that accompany a mild concussion (Field et al., 2003) and are costly to administer. A recently developed method that has been effective in measuring cognitive decrements associated with mild concussion is neuropsychological testing (Field et al., 2003).

A mildly concussed athlete exhibits certain cognitive decrements including memory impairment, decreased reaction time, and slower processing speed (Collins et al., 1999). Neuropsychological tests assign a quantitative value to each cognitive domain. The test results may indicate brain injury even though the athlete may report or experience no post-concussive symptoms.

Recently, neuropsychological tests have become computerized. This limits the test-retest effects inherent in the paper and pencil versions. A specific computerized test used for concussion management is Immediate Postconcussion Assessment and Cognitive Testing (ImPACT: Collins, Field, Lovell, Iverson, & Johnston et al., 2003). It is important to note that these tests are administered prior to the beginning of the season (i.e., baseline). In the event of a head injury, athletes can be re-tested and a comparison can be made with respect to their baseline scores. Recovery is monitored by comparing post-injury test results taken at different post-injury intervals until the brain is fully recovered (i.e., near 100% of baseline) and the athlete may return to play.

Neuropsychological testing is valid and reliable in testing the subtle effects of a mild concussion in the brain (Maroon, Lovell, Norwig, Podell, & Powell et al., 2000). Experts agree that neuropsychological testing is the new “cornerstone” of concussion management, taking the place of on-field grading systems (Aubry, et al., 2002). Computerized neuropsychological testing provides an individualized, cost-effective and sensitive approach to identifying and treating a mild concussion (Lovell, Collins, Iverson, Johnston, & Bradley et al., 2004). Computerized neuropsychological testing also provides a measure of both severity and recovery time for concussed athletes. In spite of the advances in concussion measurement, research on the factors that may contribute to concussion and its related outcomes is limited.

The physiological damages that occur to the brain due to head injury relate to the breakdown of cerebral blood flow and glucose metabolism (DeWitt & Prough, 2003). These changes may be particularly salient to the developing brain of adolescent athletes. High school football players may experience greater severity and longer recovery time related to concussion. Field, Collins, Lovell, and Maroon (2003) investigated memory decline in high school and college football players suffering from a mild concussion. High school athletes were at greater risk for prolonged cerebral swelling than college athletes. Moreover, concussed college athletes recovered quicker than high school athletes. Specifically, after being diagnosed with a mild concussion, high school athletes presented memory impairment for at least seven days, whereas college athletes presented impairment only for the first 24 hours post injury. The immature brain (i.e., < 19 years) may be up to 60 times more susceptible than the young adult to post concussion symptoms (Grundl, Biagus, Kochanek, Schiding, & Nemoto, 1994; Biagus, Grundl, Kochanek, Schniding, & Nemoto, 1996).

The concussed brain does not receive the required amount of glucose as a result of broken capillaries and inadequate cerebral blood flow (Bailes & Cantu, 2001). Capillaries naturally constrict and dilate during normal functioning in order to respond to changing blood pressure throughout the brain. When the brain is injured, these abilities are impaired. This impairment reduces blood pressure in the brain, by decreasing the amount of oxygenated blood that is circulated (DeWitt & Prough, 2003). Hence, recovery time from a concussion is dependent on the ability of the concussed brain to increase glucose metabolism and repair broken capillaries. During this time, the athlete will experience cognitive deficits consisting of memory impairment, as well as decreased processing and reaction time. These cognitive deficits experienced by a concussed athlete are similar to brain function declines documented in older adults (Marchal, Rioux, Peit-Taboue, Sette, & Travere et al., 1992).

Research on brain function decline has examined the suppressed memory and reaction time of aging individuals. There have been trends identified in the aging population regarding memory "loss" and slower reaction time due to the progress toward a sedentary lifestyle. A mildly concussed athlete also experiences brief memory impairment and slower reaction time. Other similarities include decreased cerebral blood flow and inadequate supply of oxygen to brain tissue. Further examination of the physiological changes that occur in the brain may help to link aerobic fitness to reduced risk and severity, or decreased recovery time from a mild concussion.

Although there is limited literature regarding factors related to concussion recovery, some studies have explored restoring cognitive function or preventing cognitive decline in older adults. Older adults who engage in physical activity on a regular basis have higher levels of oxygen and blood flow in the brain (Kramer, Hahn, Cohen, Banich, & McAuley et al., 1999). Older adults, who have experienced memory decline, have improved their memory scores on neuropsychological tests from participation in a regular aerobic exercise program (Dustman et al., 1984).

These findings have implications not only for the severity and recovery from a mild concussion, but also for concussion prevention. It is generally accepted that a concussed athlete should not engage in any strenuous physical activity immediately after a concussion. However, the initial level of aerobic fitness of an injured athlete may mitigate severity and recovery time. Two adaptations the body makes as a result of increased aerobic capacity are increased efficiency in utilizing glucose and increased stroke volume, both of which increase blood flow to the brain. Therefore, an aerobically fit athlete with highly elastic blood vessels and increased stroke volume may be less likely to be concussed, experience less severe symptoms and cognitive deficits, and recover more quickly from a mild concussion. This study provided an initial assessment of the relationship between aerobic fitness and concussion in adolescent athletes.

Purpose of the Study

The purpose of this study was to examine the relationship of aerobic fitness to concussion risk, severity, and recovery in high school football players.

Hypotheses and Exploratory Questions

This study tested the following three hypotheses:

1. Athletes with high aerobic capacity and no previous concussion will be significantly less likely to incur a concussion than athletes with low aerobic capacity.
2. Concussed athletes with a low aerobic capacity, more severe concussion, or a previous history of concussion will experience more symptoms and neurocognitive decrements than concussed athletes with high aerobic capacity, less severe concussion, or no history of previous concussion.
3. Concussed athletes with a high aerobic capacity will have quicker recovery times than athletes with low aerobic capacity.

In addition, this study will investigate the following exploratory questions and post-hoc analysis:

- What factors best predict concussion risk?
- What factors best predict bell-ringers?

Operational Definitions

The following terms and definitions were used in this study:

- Concussion- ""complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (p. 58); (Aubry, et al., 2001).
- Relative VO_2 Max- The relative rate of oxygen uptake is typically given by the units, milliliters per kg of body mass per minute (ml/kg/min). This form is used to compare the estimated VO_2 of individuals who vary in body size. (American College of Sports Medicine [ACSM], 2002).
- Aerobic fitness- High aerobic fitness will consist of an estimated VO_2 max value of 44.2 ml/kg/min or higher. Aerobic values lower than 44.2 ml/kg/min will be defined as being low. This value is considered above the 50^{th} percentile in young adults (p.77); (ACSM, 2002). A median split was used separate high and low aerobic fitness among participants for data analysis.
- Neurocognitive performance- Scores on a battery of scientifically-validated and computerized tests (ImPACT) of memory, reaction time, and processing speed.
- Bell-ringer- a term used in football to describe the sudden onset of concussive symptoms (i.e., brief LOC, dizziness, confusion, etc…) following trauma to the head.

Limitations

Limitations for this study included the self-reporting of concussion symptoms by athletes to athletic trainers or physicians. Data collection depended on the referral of these athletes by athletic trainers in order for post-concussion assessments to be administered (i.e., neuropsychological testing). This study was also limited by the validity and reliability of participants in recording their heart rate in beats per minute prior to the submaximal estimated VO_2 field test. The fixed bench height used in the step test protocol was a limitation due to the different angles of hip flexion of the athletes when compared to the step height as a result of the variability of tallness in athletes.

Assumptions

Assumptions for this study included the honesty of athletes, trainers, and coaches in reporting and referring all possible concussions for post-neuropsychological testing. It was assumed that the health status of each athlete was accurately assessed by the respective team physicians prior to the start of the season.

Delimitations

Delimitations of this study included that the study was comprised of data from only four private high school varsity football programs in the greater New Orleans area. The ages of participants was delimited to the range of 14 to 18 years of age. The time frame of data collection consisted of only one season which was approximately four months in length. This study included only physically healthy participants as indicated by medical release from a physician prior to the start of football practice.

CHAPTER II

REVIEW OF LITERATURE

Introduction

This chapter provides a review of the extant literature pertaining to concussion and the factors influencing concussion among adolescent athletes, particularly football players. It reviews concussion and how it occurs in American football, assessing concussion, neuropsychological testing, and factors related to this injury with regards to aerobic fitness. First, a general overview of concussion is provided.

Concussion Overview

Sports medicine researchers have identified and quantified many different types of sports injuries over the past few decades. Most injuries, such as an ankle sprain or dislocated elbow, have observable characteristics (e.g. edema, impaired ROM) that are easily identified by a trainer or coach. Concussion represents an injury that is not easily identified by sports medicine personnel, as it occurs entirely within the confines of the brain. A concussion is defined as "a trauma-induced alteration in mental status that may or may not involve a loss of consciousness" (Crump, 2001). The concussed athlete's signs and symptoms are the only indication to medical providers that a change in mental status, although invisible to the naked eye, has occurred in the brain. To understand how concussions affect the brain, one must understand the underlying neurochemical processes associated with this organ.

The brain contains cranial nerves, which are responsible for activities a person engages in everyday. These nerves carry and receive messages that allow normal interactive functioning throughout the body. Within the skull, blood and spinal fluid surround the brain. An injury to the head, such as helmet-to-helmet contact, causes the brain to bounce up against the skull. This occurrence may cause a tearing or twisting of different structures found in the brain and also cause blood vessels to break. The normal flow of messages within the brain is broken down, which then causes a disruption of brain signals.

A person who is in a normal state of consciousness has a stable interaction of cortical, subcortical, and brain stem nuclei. For normal consciousness to be maintained, the reticular activating system extends throughout the brain stem and interacts with the hypothalamus and cerebral hemisphere to complete a normal feedback loop. When a concussion occurs, this interaction between these parts of the brain is interrupted, therefore causing a change in mental status (Bailes & Cantu, 2001).

Concussions that occur in football are typically the result of an acceleration-deceleration impact. This type of impact is also known as Translational (i.e., linear) impact. The acceleration half of the injury occurs from receiving a direct blow to the head. This is essentially the skull rebounding, or accelerating, from an oncoming force such as a helmet-to-helmet hit in football. The deceleration half of the injury occurs when the skull comes in contact with a stationary object, which causes the skull to stop moving with the brain still in motion.

As the head of an athlete bounces off of, or absorbs the impact during a tackle, the head may jolt forward, backward, or twist. At this point, the brain lags behind and rebounds off of the skull repeatedly until it settles inside the skull. As a result of the brain bouncing off of the inside of the skull, an excitatory neurotransmitter, glutamate, is released in a cascade of neurochemicals. As a result of this response, an excess of chemicals present in brain neurons dump large amounts of potassium in addition to uptaking calcium and sodium ions. This event creates an ionic imbalance, or cascade. The brain will then attempt to correct this imbalance by activating sodium-potassium pumps, which are driven by utilizing energy from glucose metabolism. This results in the brain burning an enormous amount of glucose when concussed and sodium being retained in the brain cells, which causes water retention. This sequence of events may cause cerebral edema, which can be fatal in extreme cases (Bailes & Cantu 2001; Cantu, 1992).

When the ionic balance is restored, neurons shut down. Glucose metabolism in the brain drops to 50% below normal, resulting in a depressed state which can last up to 10 days (Collins et al., 1999). Symptoms from concussion fade as glucose metabolism returns to normal.

Concussion in Football

Many studies have attempted to examine the prevalence and incidence rates of concussion among high school football players. There has been some discrepancy among reported figures and statistics throughout literature. This discrepancy results from different methodologies in collecting data. One methodology consists of examining concussion per 1000 athletic exposures. This is defined as one athlete being exposed in one game or practice in which there is contact, or the possibility of being injured. Another common methodology uses a method of reporting injuries per 100 players. This method does not take into consideration the relative amount of exposure for injury to take place. Some studies also include practices where there is no contact such as "walkthroughs" or "pre-game" events. These practices are usually held without pads and are non-contact in nature. Including these types of practices in data collection can inflate the incidence rate as to overestimate the risks involved for sustaining injury. An example of this is found in a study by Zemper (2003). This study reported that the incidence rate of concussion at the high school level was 3.71 concussions per 100 team members. The rate for college football players was 4.21 concussions per 100 team members. These rates seem somewhat different at first glance, but actually they are similar. College football typically involves more practices and games than high school football. Therefore, the exposure level of college athletes is different than in a high school age group. When exposures are not taken into consideration, the statistics can be misleading.

Nonetheless, there are an estimated 1.08 million college and high school participants in American football every year. High school football accounts for 63% of all concussions reported by Powell and Barber-Foss (1999). There are an estimated 43,000 concussions among high school football players annually (Zemper, 2003). Research indicates that one out of every five high school football players will experience a concussion during their playing career (Sramek, 1998).

It is common for researchers to compare the incidence and prevalence of concussion between football players at the college and high school level. One interesting statistic is the similar incidence rate of high school football (5.6%) and Division III college football (5.5%): (Guskiewicz et al., 2003). These incidence rates are twice as high as Division I and II. Division I and II college football programs typically contain the more elite or skilled football players. Decreased incidence at this level could result from possible lack of exposure during practice and better coaching techniques. Therefore, commonalities between high school and Division III football teams consist of players playing both , offense and defense, skill level, quality of equipment, and availability of medical personnel on staff (Zemper, 2003).

Although attempts to limit concussions at the high school level have been implemented such as rule changes (e.g., making spearing illegal), little attention has been paid to the factors associated with concussion risk, severity, and recovery. The speed of recovery is thought to be similar with age, but findings indicate that high school athletes demonstrate a slower neuropsychological recovery after concussion, especially in mild cases (Fields et al., 2003). College athletes have demonstrated memory deficits within 24 hours, while memory dysfunction in high school athletes can last up to seven days or more. This may prove significant that high school athletes cannot bounce back from a concussion as quickly as college athletes.

Many football players battle recurrent injuries from season to season. In a highly physical sport, a nagging ankle or shoulder injury that doesn't seem to go away is common. However, when an athlete suffers a concussion, consequences from this injury may affect medical decisions on his behalf for the rest of his career. When a high school football player sustains a concussion, he is three times as likely to sustain another concussion in the same season (Guskiewicz et al., 2003). An athlete with a previous history of a concussion will exhibit more symptoms when assessing concussive symptoms prior to the start of a season than an athlete with no symptoms (McCrea et al., 2004). This uncovers that the effects from sustaining a previous concussion are cumulative (Iverson et al. 2004). High school athletes who have sustained multiple concussions are at a greater risk for worse neurobehavioral outcomes in the event of another concussion.

Assessing Concussion

Athletes experience a wide variety of symptoms during the 10 days of brain recovery as previously mentioned. However, a mild concussion is usually only attended to if effects and symptoms are reported by the injured athlete. In a study by McCrea et al. (2004), 1532 concussions were examined. Only 15% of athletes who had sustained a mild concussion reported any symptoms. Athletes may not report symptoms because they think what they are feeling is not severe enough to warrant medical attention, and are often afraid they will be withheld from competition, or do not have an awareness of the consequences of their symptoms (McCrea et al., 2004). Football players in general are viewed as being tough, durable, and often expected to play through pain. A "nagging" headache after an intense collision is frequently referred to having one's bell "rung." This symptom usually lasts for a brief period of time, after which the athlete may report no symptoms, and returns to play. However, studies have shown that even though symptoms seem to be short-lived, athletes show cognitive impairments up to 24 hours after injury (Lovell et al., 2004). Concussions often go without proper medical attention due to the attempt of the athlete to fit this description, or stereotype, of a football player.

Experiencing loss of consciousness is a definite predictor of trauma to the brain and results in immediate medical attention. Loss of consciousness is defined as a brief coma in which the athlete is unresponsive to external stimuli. However, identifying mild and moderate concussions involve different symptoms. An athlete may experience these symptoms throughout the course of an entire high school football season.

There are many neuropsychological effects and symptoms that accompany a mild concussion, or multiple traumatic brain injury (MTBI). These symptoms can range from nausea, fogginess, dizziness, headaches, vomiting, loss of balance, and posttraumatic amnesia (PTA) as reported by Lovell et al. (2003). Posttraumatic amnesia can be divided into two types: retrograde and anterograde. Retrograde amnesia is defined as a "partial or total loss of the ability to recall events that have occurred immediately preceding the brain injury" (Aubry & Cantu, 2002). Anterograde amnesia is a deficit in forming new memories after the head injury. Disorientation or confusion is defined as an impaired awareness and orientation to one's surrounding. Posttraumatic amnesia is often confused with disorientation; however, disorientation has nothing to do with memory loss as amnesia does. These symptoms can be experienced in isolation or in combination with other symptoms in a mild or moderate concussion.

Previous research has attempted to examine the presence and duration of these symptoms to help identify a mild concussion. Athletes who suffer a concussion will exhibit symptoms during competition, which can be reported on the field of play (McCrea et al., 2004). These symptoms that are reported by athletes have shown trends, which have been shown to predict mild concussion (Cantu, 2001).

Amnesia and loss of consciousness have been the basis for concussion management in the past (Guskiewicz et al., 2003). During competition, concussion has typically been the possible diagnosis for athletes who mainly complain of amnesia or brief LOC. Research has looked at these two on-field symptoms and has concluded that amnesia may be more predictive of post-concussive symptoms than loss of consciousness (Collins et al., 2003). Athletes who have trouble recalling events and experience difficulty remembering significant things, usually have experienced a more severe concussion that has a longer duration of symptoms when compared to someone who had experienced a brief loss of consciousness (Collins et al., 2003).

Research has concluded that athletic trainers often overlook one aspect of on-field symptoms. Athletic trainers have neglected such reported symptoms as headache, brief dizziness, disorientation, and confusion only to give attention to amnesia and loss of consciousness. However, studies have shown that in a sample of 1003 reported and diagnosed concussions, loss of consciousness was reported only in 8.9% of injuries and 27.7% of the total injuries reported amnesia (Guskiewicz et al., 2003). The remaining percentage of concussions presented symptoms of headaches, nausea, confusion, dizziness, fogginess, disorientation and vomiting. One study examined this remaining percentage and found that symptoms, that did not consist of amnesia or LOC, which lasted up to two days post-injury, were ten times more likely to have experienced some sort of amnesia and failed to report it (Collins et al., 2003). This helps to suggest that a headache is a more frequent predictor of a mild concussion than amnesia or LOC.

The duration of the presence of on-field symptoms has been found to predict the lasting effects of a concussion. A recent study analyzed groups of concussed athletes who had symptoms lasting less than five minutes and more than five minutes. The findings suggest that the lasting effects of a mild concussion could last longer than seven days if the on-field symptoms last more than five minutes (Lovell et al., 2003). This data may assist a trainer or team doctor in follow-up medical care with symptomatic concussed athletes.

When an athlete experiences these symptoms and reports them to team trainers and doctors, there are certain steps taken in managing a concussion. These steps have purposes that consist of assessing the severity of the injury and determining whether the athlete can return to competition. To assess a concussion, there have been multiple grading scales used in an attempt to classify the different degrees of this injury. The three most common grading scales used have originated from the American Academy of Neurology, Cantu's Grading System, and the Colorado Medical Society Guidelines (Collins et al., 2004). All three grading systems classify a concussion into Mild (Grade I), Moderate (Grade II), and Severe (Grade III). Grades of concussions provide a uniform assessment of head injury. Return-to-play guidelines are specifically recommended with each grade of injury. Cantu's grading system is widely accepted throughout the sports medicine field.

According to Cantu's grading scale, the amount of amnesia reported by the athlete and the longevity of the loss of consciousness are taken into consideration when severity assessments are made. If an athlete experiences any loss of consciousness the injury is automatically graded moderate, or Grade II. Loss of consciousness over five minutes or post-traumatic amnesia lasting longer than 24 hours will warrant a Grade III or severe concussion (Bailes, 2001).

Neuropsychological Testing and Concussion Assessment

Since cognitive recovery is suggested as being delayed after a 24-hour post injury time period, return-to-play decisions are often difficult to make. Athletes may report symptom free after 15 minutes on the sideline; however there is still injury with regards to the brain. Post-concussive symptoms may go unnoticed and therefore be hard to see by coaches, trainers, and physicians (Lovell & Collins, 1998). These fifteen minutes may not really disclose the effects of the injury, and high schools typically do not have the medical support a college program has. Therefore these Grade I concussion guidelines may not be conservative enough to ensure the athlete's safety. Research has suggested that guidelines concerning this issue need to be more strict (Lovell et al., 2004).

Injury can evolve over subsequent days and can only be detected by a neuropsychological test. Mild concussions can be hard to identify because CT scans, and MRI's are found to be insensitive to injury (Fields et al., 2003). This evolution of symptom reporting undergoes a significant change and is backed by neuropsychological testing.

Concussion management is moving towards a more individualized approach in assessing and treating this injury (Lovell et al., 2003). Not all athletes have the same symptoms and therefore treatment should be more specific towards each athlete. There is much difficulty by medical personnel in deciding "when" it is safe for an athlete to return to play. One direction that research is taking in assessing concussions is neuropsychological testing. Neuropsychological testing is a cognitive assessment that measures different domains of cognitive functioning (Lovell et al., 2003).

The best approach to concussion management is early recognition of post concussive symptoms and prevention of additional concussive injuries (Collins & Lovell, 1998). A test that is currently being used by organizations such as the NFL and NHL is ImPACT, which was the first computerized test to evaluate the severity of a head injury (Aubry & Cantu, 2002). ImPACT is a 20-minute test that provides data on the cognitive functioning of an injured athlete. Test recommendations consist of administering it before the season (baseline), and re-administering it within 24-48 hours post-injury or until asymptomatic. After obtaining the results after post-injury evaluation, comparisons can be made to baseline data and decisions can be made on the severity of the injury while monitoring the progression of recovery in the athlete. The athlete cannot lie to the computer program, and often an athlete will try to "beat" the software in order for clearance to participate in competition. When the injured athlete does his best on this assessment, more valid and reliable results are collected. Using neuropsychological tests, such as ImPACT, recovery time and patterns can be identified and also ensure that deteriorating effects are not taking place (Lovell, 2004). Comparing self-reporting symptoms to neuropsychological test results show that memory decline may still be present when off-field symptoms are not (Lovell, 2003).

Grade I concussions, or moderate head injury, greatly benefit from additional assessment by administering a neuropsychological test because of the difficulty in identifying the symptoms. A Grade I concussion recommends a minimum of 15 to 20 asymptomatic minutes before returning to competition. Injuries involving a headache require a 20-minute removal from competition until asymptomatic. Clinical guidelines recommend one week-removal from activity regarding the occurrence of a mild concussion (Guskiewicz et al., 2000).

The dilemma often occurs when a starting player, on whom the team's success greatly depends on, is injured. In this situation, should clinical guidelines concerning mild concussions be followed? In a study that surveyed the length of time dismissed from activity, the results found that one-third of all high school football players returned the same day or game as the injury occurred (Guskiewicz et al., 2000). This same study also examined return-to-play decisions made by trainers and doctors compared to coaches' discretion. The findings stated that when the coach made return-to-play decisions regarding mild concussions, 69% of injuries returned to competition. Return-to-play decisions made by certified trainers and doctors found that only 30% re-entered competition. The mean recovery time for both coaches and trained medical professional was 13 minutes. This is two minutes short of clinical guidelines (Guskiewicz et al., 2000). This study suggests that readmittance to competition is very subjective in nature and neuropsychological testing can add objectivity to decision making.

The ImPACT neuropsychological assessment is proven to be sensitive to mild concussion by measuring different cognitive domains such as attention, memory, reaction time and processing speed (Iverson, Lovell, & Collins, 2003). This test is designed to be brief reliable and be more efficient than traditional neuropsychological tests to analyze the subtle changes an athlete undergoes in the immediate periods after a concussion.

Even though ImPACT seems to be valid and reliable, there are some limitations to neuropsychological testing in general. One limitation is the phenomena of practice effects. Practice effects are the natural learning curve or improvement in test results that come from becoming accustomed to the testing protocol. Varying stimuli of presentation can minimize these effects. A recent study looked at how practice effects were controlled for with regards to the ImPACT testing modules and found that all versions of ImPACT controlled for practice effects (Iverson et al., 2003).

Another limitation of neuropsychological testing is encountering athletes with learning disabilities and ADHD. These two conditions are common among high school athletes. The issue at hand is that symptoms exhibited from a history of concussion are similar to symptoms presented from a learning disability. Research has taken these two variables and examined the effects they have on neuropsychological testing and found that there is a relationship between learning disability and concussion history. It has also been hypothesized that athletes with a learning disability have less brain reserve to begin with, therefore their neuropsychological test results are lower (Collins et al., 1999).

Factors Related to Concussion

Athletes who have experienced a history of concussion are more susceptible to sustaining another concussion or head injury. Studies show that there is a relationship between the number of years of participation in football and the number of concussions sustained (Collins et al., 1999). Athletes who have had a concussion in the previous five years prior to competition have a six times greater chance of a repeat concussion. Statistics also indicate that 1 in every 35 players with no history of having a concussion will sustain a concussion over the course of a season. Comparing this to athletes who have had a prior concussion, 1 out of every 6 players will sustain a concussion (Zemper, 2003). These data suggests that previous concussions are a stable predictor of repeat occurrence at the high school level.

Literature has also stated that concussions have been found to have a greater chance of occurring in a game setting rather than practice (Zemper, 2003). Multiple traumatic brain injury (MTBI) rates are 11 times higher for games than practice as reported by Powell and Barber-Foss (1999). This might be a result of decreased motivation, coaches limiting contact during drills, and practicing without pads.

There has been speculation that certain positions in football are more susceptible to concussions than others. Powell and Barber-Foss (1999) found that MTBI occurred around making a tackle or being tackled by an opponent. They also found that linebackers experienced the most concussions with regards to playing a specified position. Collins et al. (1999) found that quarterbacks and tight ends have the highest rates of prior concussions, while in a more recent study, he found that running backs, fullbacks, kickers, and punters experience the lowest rates of prior concussions (Collins et al., 2000).

Factors Related to Aerobic Fitness and Concussion

Coaches, trainers, researchers, and athletes interested in concussion all have to agree on one aspect, concussion will continue to happen. The nature of the game of football, and how it is played, will always predispose athletes to the risk of sustaining a concussion. If research could uncover a method of improving recovery time and severity, then concussion management could make advances with regards to prevention. One strategy extrapolated from older adults in literature is to restore vasodialatory and vasoconstrictive properties to the capillaries found in the brain (DeWitt & Prough, 2003).

As mentioned before, the brain, just like any other organ in the body, is made up of tissue that uses glucose for fuel and also contains blood vessels, which make up the networking components of cerebral blood flow. The injured brain cannot get the required demand of glucose as a result of broken capillaries and inadequate cerebral blood flow. Autoregulation of vasodilatation and vasoconstriction of these capillaries are impaired during this time of injury (DeWitt & Prough, 2003). This impairment reduces blood pressure in the brain, therefore decreasing the amount of oxygenated blood that is circulated (DeWitt and Prough, 2003). This entire process slows the recovery period of a concussion.

Aerobic fitness is an integral part of a healthy functioning person. Being aerobically fit predisposes the body to make certain adaptations as a result of exercise to improve our overall health status. Some adaptations consist of increased efficiency of the circulatory system, which provides the body with such benefits as lower resting heart rate, increased stroke volume, and improved elasticity of blood vessels. In response to DeWitt and Prough (2003), aerobic fitness level may be a predictor of improved concussion recovery.

Previous literature relating aerobic fitness and concussion recovery is somewhat limited. However, there are many studies and findings concerning aerobic exercise training and improved neuropsychological function. These studies mainly concern older adults and the cognitive decline associated with aging. There has been published evidence that older adults have a decline in oxygen transport to the brain, neurotransmitter synthesis, and cerebral metabolism (Marchal et al., 1992). This evidence is similar to the findings and effects of a head injury in football. Therefore, studies that analyze aerobic fitness and aging have a common link to the effects of a mild concussion consisting of decreased cerebral blood flow and metabolism.

Literature suggests that chronic exercise might result in a more stable increase in oxygen delivery to the brain (Dustman, Emmerson, & Shearer, 1994). Dustman (1984) also reported findings which examined the cognitive successes experienced by more aerobically fit individuals than a non-active control group. These findings provide substantial evidence that suggests the benefits that aerobic fitness has on the cognitive function of the brain. If cognitive function of the brain is improved, there is no hindrance on the brain, which may be a result of an injury such as possible concussion.

This hypothesis regarding improved cognitive function due to aerobic fitness has also been exercised in a laboratory study including rats. When rats exercised on a running wheel, capillary density in the cerebellum was found to increase (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990). Aerobic exercise should be expected to have the same effects in humans. If these finding are consistent, then more aerobically fit athletes may have an increased oxygen delivery during cognitive impairment or "concussion recovery stage." With this increase in oxygen delivery and efficiency, athletes who have a higher estimated VO_2 max may benefit by having a more expedited recovery from mild concussion. The current study attempted to further explore this idea with a comparison of aerobic fitness to concussion risk, severity, and recovery in high school football players.

Summary

In summary, there is a high occurrence of concussions in American football especially at the high school level. This injury is important among this age group due to the fact that the brain is not fully developed until the age of 18. Assessing concussion has always been difficult due to the nature of this injury. Neuropsychological testing offers a good measure of the effects, severity, and recovery time of this injury. One factor that may play a role in the likelihood and effects of concussion is aerobic fitness.

CHAPTER III

METHOD

Design

This study used a prospective, baseline/post-injury repeated measures design to examine the relationship between aerobic fitness and concussion severity, recovery, and incidence.

Participants

Participants included 158 high school football players from four private and parochial schools located in the greater New Orleans area. The ages of participants ranged from 14-18 years. To be included in the study each school was required to employ a full-time athletic trainer on staff during both practices and games. All participants were considered physically healthy by completing their respective physical examination form with medical clearance by a physician prior to the start of the season. Participants indicating on ImPACT any previous history of learning disability, ADD/ADHD, brain disease or disorder (i.e., epilepsy, brain surgery, meningitis, etc…) and/or substance abuse were excluded from the study. The researcher obtained appropriate human subjects approval from the University of New Orleans Human Subjects Committee prior to the study. Written parental/guardian consent and participant assent was also collected from each participant prior to their participation in the study.

Measures

Demographics and exposure. Participants were asked to complete a questionnaire regarding height, weight, position, age, grade, and playing status (i.e., starter or nonstarter). Information regarding exposure (i.e., attendance and participation) for each athlete was also obtained weekly from athletic trainers.

Aerobic fitness. The study followed the three-minute step test as used by Francis (1990). The three-minute step test is considered one of the oldest field tests for predicting oxygen consumption with regards to recovery heart rate. Instruments used for this protocol consisted of a 16'' step bench, data recording forms, stopwatch, and metronome. The protocol for this test required subjects to step up and down from a platform for a total of three minutes. Subjects stepped at a rate of 26 steps per minute for the three-minute period. This rate was implemented by a metronome device, which was pre-set at a reading of 104 to establish the stepping rate. Subjects were instructed to immediately stop stepping at the termination of the three-minute period. Heart rate was found for 15 seconds from 5 to 20 seconds of recovery. The step test was easy to administer, time and cost efficient, and did not require a laboratory setting for implementation. The three-minute step test has a correlation coefficient of .81 at 26 ascents/min stepping frequency when compared with the Bruce protocol (Francis & Brasher, 1992). This study tested multiple participants at a time, something that cannot be logistically completed in the constraints of the current study by using other clinical VO_2 max assessments (e.g., treadmill tests).

Concussion reporting. Athletic trainers and physicians reported and referred to the researcher any observable or self-reported indication of a mild concussion in any athlete. Physical signs of mild concussive symptoms can range from headache, dizziness, nausea, confusion, disorientation, and any form of posttraumatic amnesia (Collins et al., 2003). Athletic trainers were urged to implement sideline assessments if any player was suspect of sustaining a concussion. The University of Pittsburgh Medical Center (UPMC) Sports Concussion program developed a sideline assessment card for testing any cognitive decrements that an athlete may experience when concussed (see Appendix A). These on-field markers warranted referral to the researcher for post-injury neurocognitive testing. Concussions that presented profound symptoms (i.e., LOC, dizziness, confusion, PTA, etc…) on the field, or at the time of injury, were classified as severe. Athletes who sustained a mild or severe concussion were referred to the researcher for post-injury neuropsychological testing using ImPACT. More severe closed and open head injuries were excluded from the study and were dealt with by each school's medical staff in accordance with the school's policies.

Computerized neuropsychological testing. The ImPACT test and symptom inventory neuropsychological testing software is a tool that allows for individual concussion assessment and management (Collins et al., 2004). This test was a time-efficient, sensitive, valid, and cost-effective way to evaluate concussion. The ImPACT test consisted of a battery of computerized tests that comprised six different modules. The modules consisted of attention span and working memory, visual memory and verbal memory, sustained attention, selective attention, reaction time and response variability, and non-verbal problem solving. The test was administered to 20-30 participants at the same time using networked computers. This 20-30 minute self-paced test also included questions about symptoms, concussion history, and other related factors (e.g., learning disability, mental health history). In a study by Iverson, Lovell, and Collins (2003), the reliability measure of this testing program indicated that there were no practice effects over a two-week test-retest interval. This study also found correlation coefficients for the composite scores of each test battery ranging from .65 to .86. The composite scores associated with each test battery vary for each module. Verbal and visual memory scores are presented as the percentage correct, while motor speed and reaction time is presented in seconds.

The test was administered at baseline (i.e., preseason) to all participants, and then again to any participants who incurred a suspected mild concussion. Post concussion administration was conducted at 48-72 hours post injury and again every 48 hours thereafter until the athlete returned to baseline. Concussion severity and recovery was monitored in conjunction with the UPMC Sports Concussion program's assistant director, Dr. Michael Collins and each school's medical staff.

Procedures

Permission from pertinent school administrators, coaches and medical staff was obtained prior to data collection. Parental consent and participant assent was also obtained from each participant at a brief informational meeting with each team. After each school consented to participate in the study, a site analysis of each school was conducted by the researcher prior to the beginning of the study. This analysis included obtaining a fixed-height bench, which was 16 inches in height for the 3-minute step test. Gymnasium bleachers were used if the height requirements were met measuring from the floor to the top surface of the step. This enabled researchers to accommodate more than one athlete at a time for the aerobic baseline assessment. Computer labs and servers were also examined to make sure that they met the minimum hardware and software requirements to run the ImPACT program. Pilot tests of the three-minute step assessment were conducted with five volunteers who were excluded from the study. All athletic trainers were instructed in the methods of identifying mild concussive symptoms presented by their respective athletes. Athletic trainers were given the sideline assessment card, and had the opportunity to ask the researcher any questions on what constituted referral for post-injury testing. Coaches were responsible for submitting exposure information about players' attendance and participation in practice or games. The form for this exposure documentation can be found in Appendix B.

Prior to baseline testing, participants completed a written demographic form including information on age, height, weight, position, grade, and playing status (see Appendix C). Aerobic fitness was assessed using the three-minute estimated VO_2 sub-maximal step test described earlier. Participants were divided into groups of 10-15 to complete the test. The researcher instructed subjects on how to assess their heart rate in beats per minute using the palpitation method to find their pulse prior to the start of the test. This instruction took place in a lecture setting and subjects had the opportunity to ask questions and receive assistance in finding their pulse for a 15 second count. Each subject verbally indicated to the researcher that they were able to find their pulse. The research team followed the step test protocol as described in Francis (1990) to implement the aerobic fitness assessment. The data were recorded and inserted into an equation to estimate VO_2 max (see Appendix D). Approximately 24 hours after the aerobic fitness testing, neuropsychological testing took place. Baseline ImPACT testing was administered in the computer labs at each respective school. All ImPACT tests were administered at the same time to groups of approximately 20-30 participants depending on the available number of computers.

During the course of the competitive football season, player attendance for the entire week and the total number of practices and games players participated in was obtained from coaches by the researcher via telephone. During the season, all players who incurred a suspected concussion based on physical markers present in the athletes were referred by athletic trainers or physicians to the researcher for post-injury neuropsychological testing. To insure that all concussions were reported, the researcher called each athletic trainer twice per week to remind them and determine if any potential concussions have occurred that were not immediately reported. All trainers and medical staff were cooperative with the retest protocol implemented by the researcher. Any players who incurred more serious closed (e.g., subdural hematoma) or open (e.g., skull fracture) head injuries were not tested, as they required immediate emergent medical care from the team medical staff or other medical providers. Within 24-72 hours of a concussion, each concussed player completed a post-concussion ImPACT test at his school. Follow-up ImPACT tests was administered every 24 to 72 hours until the concussed athlete was asymptomatic and returned to 100% of his baseline neurocognitive performance, at which time the player was permitted to return to play.

After the season, players were given a questionnaire (see Appendix E) to assess any “bell-ringer” phenomena and unreported concussive symptoms. This questionnaire was used to identify possible concussions that were not disclosed or reported to coaches or trainers during the season.

Data Analysis

All data were reported anonymously or as group data with no specific identifying information. Data was analyzed using the Statistical Package for the Social Sciences

(SPSS) 11.5 software. Demographic information was summarized using descriptive data. Concussion incidence rates were calculated. Hypothesis 1 was assessed using the odds ratios from a logistic regression (LR) with aerobic fitness as the predictor and concussion status as the outcome. Hypothesis 2 was tested using a Repeated Measures MANOVA comparing the baseline and post-concussion symptoms and neurocognitive scores of high and low aerobic fitness levels. Hypothesis 3 was tested using an independent t-test with aerobic fitness as the predictor of estimated VO_2 max and recovery time as the outcome. A trend analysis for recovery curves for the 2 groups was also conducted. Exploratory questions 1 and 2 were assessed using a series of LRs. ImPACT data will be analyzed by examining composite scores of verbal memory, visual memory, motor speed, and reaction time (see Table 1). Statistical significance was set at a $p \geq 0.05$ level for this study.

Table 1

ImPACT Composite Module Descriptions, Values, and Value Range Classifications.

ImPACT Composite Module	Description of Test	Value	Value Range Impaired – Very Superior
Verbal Memory	Comprised of the average of Total memory percent correct; Symbol Match-Total correct hidden symbols; and Three-letters total percent of total letters correct.	Percent Correct	$\leq$ 0.63 – 100.00
Visual Memory	Comprised of the average of the Design memory, total percent correct score and the X's and O's, total correct-memory score.	Percent Correct	$\leq$ 0.49 – 100.00
Motor Speed	comprised of the average of following scores: X's and O's-total correct (interference)/4; Three-letters-Average counted correctly*3.		$\leq$ 16.20 – $\geq$ 50.30
Reaction Time	Comprised of the average of the following scores: X's and O's-Average correct RT (interference); Symbol Match-Average correct RT/3 and; Color Match-Average correct RT.	Time in Seconds	$\geq$ 0.76 – $\leq$ 0.44

CHAPTER IV

RESULTS

Introduction

This chapter begins with a presentation of the demographic data from this study. Baseline data are then discussed in order to provide a means of comparing baseline scores for the participants in this study to their respective retests, and also to normative data from ImPACT. The epidemiological rates of concussion will then be presented followed by an evaluation of each hypothesis and an exploratory question. Finally, several post-hoc analyses will be reviewed.

Demographic Information

There were a total of 158 participants included in this study from four private and parochial urban schools. Demographic information was collected using the preseason questionnaire and ImPACT test. The mean age of the participant pool was 15.77 years (SD= 1.15). Out of the total number of participants 17% were freshmen (n= 27), 34% were sophomores (n= 52), 24% juniors (n= 38), and 23% were seniors (n= 37). The mean years of experience in football were 1.89 (SD=1.56). Approximately 86% of participants were right handed (n= 126), 9% were left handed (n= 15) and the remainder (n= 6) were ambidextrous.

Prior to the start of the season aerobic fitness was assessed using the three-minute step test described earlier. The aerobic condition of the participants was only assessed once during the course of the data collection period. Due to the anaerobic nature of football, aerobic fitness was assumed to stay consistent throughout the season. The mean estimated VO_2 max value was 36.29 ml/kg/min (SD= 11.32). Only 27% (n= 42) of participants were classified as high estimated VO_2 max based on the criteria (estimated VO_2 max= 44.20 ml/kg/min) provided by (ACSM, 2002). Consequently, a median (estimated VO_2 max= 36.72 ml/kg/min) split method was used to create high and low estimated VO_2 max classifications. Using this method, there were 83 participants who had a low estimated VO_2 max and 75 who had a high estimated VO_2 max.

Concussion Rates

Twenty players reported having at least one concussion in this study, which represents approximately 13% of the total sample. Thirty-five percent of the concussed participants incurred two concussions during the season. Participants were only counted once as either being concussed or not concussed, therefore a second concussion did not consider the participant as counted twice. Of the reported concussions, seven were classified as being severe based on the on-field observation of symptoms at the time of injury. On-field symptoms that indicated a severe concussion included profound confusion, dizziness, balance problems, PTA, and/or LOC. A total of 18% of the participants reported a previous concussion (n= 29), 82% (n= 129) reported never having had a concussion before the study. The mean number of previous concussions for the total sample was 0.32 (SD=0.92).

Concussion rates and exposures were calculated as concussions per 1000 total exposures (game and practice) and per 100 participants. An exposure represented participation in any activities involving contact in practice or participation in any part of a game. There were 7,612 total exposures during this study. The concussion incidence rates for this study were 2.63 concussions per 1000 exposures and 12.66 concussions per 100 participants.

Participants were divided into groups according to their injury status (e.g., concussed or non-concussed) with regards to factors examined in this study. The three factors examined in data analysis were severity, estimated VO_2 max, and previous concussion. The number of participants that made up each group can be found in Table 2.

Table 2

Number of Participant Groups for Severity, High/Low Estimated VO_2 Max, and Previous Concussion for the Total Sample (N= 158).

Factor	Description	Groups
Severity	On-field symptoms	Severe (n=7) Non-severe (n=13)
Estimated VO_2 max	Numerical values assigned to participants to classify them according to their aerobic fitness.	High (n= 75) Low (n= 83)
Previous Concussion	Self-reported by ImPACT questionnaire	Previous Concussion (n= 29) No previous concussion (n= 129)

Baseline Data

A series of MANOVAs were used to examine differences in baseline ImPACT scores and symptoms between: (a) concussed and non-concussed, (b) high and low estimated VO_2 max, and (c) previously concussed and not previously concussed participants. Baseline ImPACT module and symptom scores and norms are described in

Table 3. In general, the baseline ImPACT module scores were below the average than normative data for this population. According to normative data classification, the participants in this study would be classified as average.

Table 3

Descriptive Baseline ImPACT Module and Symptom Scores for the Total Sample (*N*= 158).

ImPACT Module	*Mean*	*SD*	ImPACT Norms Ages (13-15)	ImPACT Norms Ages (16-18)
Verbal Memory	0.79	0.10	0.87	0.86
Visual Memory	0.69	0.14	0.78	0.79
Motor Speed	31.90	7.98	33.95	37.78
Reaction Time	0.57	0.11	0.57	0.53
Symptom Total	10.49	10.87	NA	NA

$^{*}p \leq 0.05$

A comparison of concussed and non-concussed participants in the current sample indicated no significant differences in baseline ImPACT module scores and symptoms. Similarly, a comparison of previously concussed and non-previously concussed participants revealed no significant differences in baseline ImPACT module scores and symptoms. There were also no significant differences in baseline ImPACT module and symptom scores between high and low estimated VO_2 max groups. The data suggest that the participants were similar in regard to baseline ImPACT module scores and symptoms, regardless of these potential confounding factors. Hence, any differences between baseline and post concussion testing scores and symptoms would likely be due to concussion.

Evaluation of Hypotheses

Hypothesis 1- Athletes with high aerobic capacity and no previous concussion will be significantly less likely to incur a concussion than athletes with low aerobic capacity. To assess this hypothesis, ORs were calculated for the possible risk factors of high/low estimated VO_2 max and history of previous concussion. The OR for low compared to high estimated VO_2 max groups was non-significant, although it was in the hypothesized directions. The results indicated that those low in estimated VO_2 max (n= 83) were 1.80 (*95% CI*= 0.68-4.80) times more likely to incur a concussion than those high in estimated VO_2 max (n= 75). However, this OR was not significant (χ^2= 1.43, p= .23). The results indicated that those who were previously concussed (n= 29) were 3.71 times (*95% CI*= 1.36-10.18) more likely to be concussed in the current study than those who were not previously concussed (n= 129). The χ^2= 7.16 was significant (p= .01). In summary, Hypothesis 1 was partially supported by the data, which indicated a slight, though non-significant trend for increased risk of concussion in participants low in aerobic fitness. However, as hypothesized, previous concussion was a significant risk factor for concussion in this study.

Hypothesis 2- Concussed athletes with a low aerobic capacity, more severe concussion, or a previous history of concussion will experience more symptoms and neurocognitive decrements than concussed athletes with high aerobic capacity, less severe concussion, or no history of previous concussion. A series of 2 (high/low estimated VO_2 max) x 2 (severe/not severe) x 2 (previously concussed/not) repeated measures ANOVAs were used to assess within and between subjects differences in ImPACT module scores and symptoms from baseline to 3 days post concussion. Concussion severity and previous concussion were included in the analysis because they have been shown to affect post concussion ImPACT module scores and symptoms. Descriptive statistics of each ImPACT module and symptom totals for high and low estimated VO_2 max, severity, and previous concussion can be found in Tables 4, 5, and 6.

Table 4

Baseline and Three Days Post-Injury Descriptive Statistics for Estimated VO_2 Max on ImPACT Module Scores and Symptom Totals.

	Estimated VO_2 Max							
	Baseline				Three Days Post-Injury			
	High		Low		High		Low	
Module	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Verbal Memory	0.78	0.09	0.75	0.13	0.75	0.16	0.76	0.12
Visual Memory	0.75	0.15	0.63	0.14	0.67	0.21	0.66	0.11
Motor Speed*	35.35	10.41	33.28	6.30	35.64	11.91	33.27	6.75
Reaction Time	0.52	0.05	0.56	0.10	0.55	0.06	0.59	0.19
Total Symptoms	7.66	8.14	12.27	10.21	13.17	14.86	17.45	13.62

*$p \leq 0.05$

Table 5

Baseline and Three Days Post-Injury Descriptive Statistics for Concussion Severity on ImPACT Module Scores and Symptom Totals.

	Concussion Severity							
	Baseline				Three Days Post-Injury			
	Severe		Non-Severe		Severe		Non-Severe	
Module	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Verbal Memory	0.80	0.10	0.76	0.13	0.74	0.16	0.80	0.12
Visual Memory	0.64	0.50	0.68	0.17	0.63	0.14	0.69	0.16
Motor Speed*	31.81	6.41	35.55	7.88	31.26	9.87	36.97	7.03
Reaction Time	0.55	0.04	0.55	0.11	0.43	0.21	0.55	0.10
Total Symptoms	15.57	11.18	10.00	11.80	22.29	14.31	11.54	10.63

*$p \leq 0.05$

Table 6

Baseline and Three Days Post-Injury Descriptive Statistics for Previous Concussion (PC) on ImPACT Module Scores and Symptom Totals.

	Previous Concussion							
	Baseline				Three Days Post-Injury			
	PC		No PC		PC		No PC	
Module	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Verbal Memory	0.76	0.10	0.80	0.10	0.78	0.14	0.78	0.14
Visual Memory	0.66	0.16	0.69	0.14	0.70	0.15	0.65	0.15
Motor Speed*	32.06	7.56	31.87	8.10	38.54	4.51	32.59	9.60
Reaction Time	0.60	0.10	0.57	0.11	0.63	0.21	0.54	0.08
Total Symptoms	14.00	13.62	10.58	10.48	19.25	11.02	12.67	13.66

*$p \leq 0.05$

Symptom Reporting. The results of a 2 (estimated VO_2 max) x 2 (severity) x 2 (previous concussion) repeated measures ANOVA indicated no significant within subjects main effects for these factors on total symptoms (see Table 7). The only significant within subject relationship was a three-way interaction between the three factors on total symptoms (*Wilk's* λ= 0.62, F [1, 12] = 7.39, p= 0.02, η^2= 0.38). See Figures 1 and 2 for a depiction of this interaction.

Table 7

Results of a Repeated Measures ANOVA for estimated VO_2 max, Severity, and Previous Concussion on Total Symptoms.

Factor	*Wilk's λ*	*F*	*Df*	*Error df*	*p*	η^2
Estimated VO_2 max	0.83	2.54	1	12	0.14	0.18
Severity	0.89	2.54	1	12	0.25	0.18
Previous Concussion	0.97	0.40	1	12	0.54	0.03

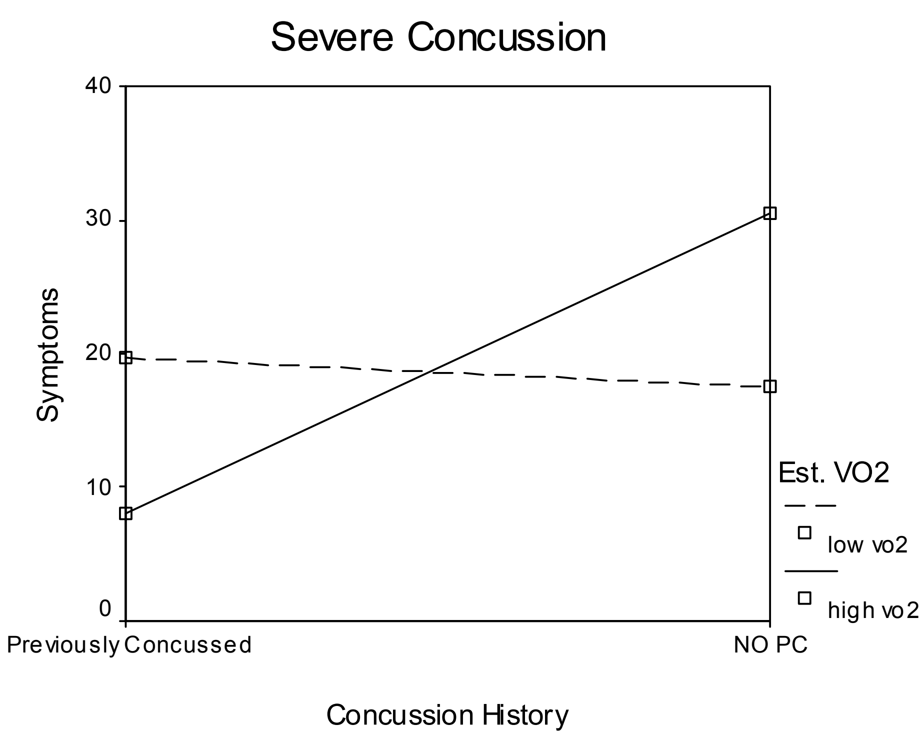

Figure 1. Interaction between estimated VO_2 max and previous concussion on total symptoms among severely concussed athletes (n= 7)

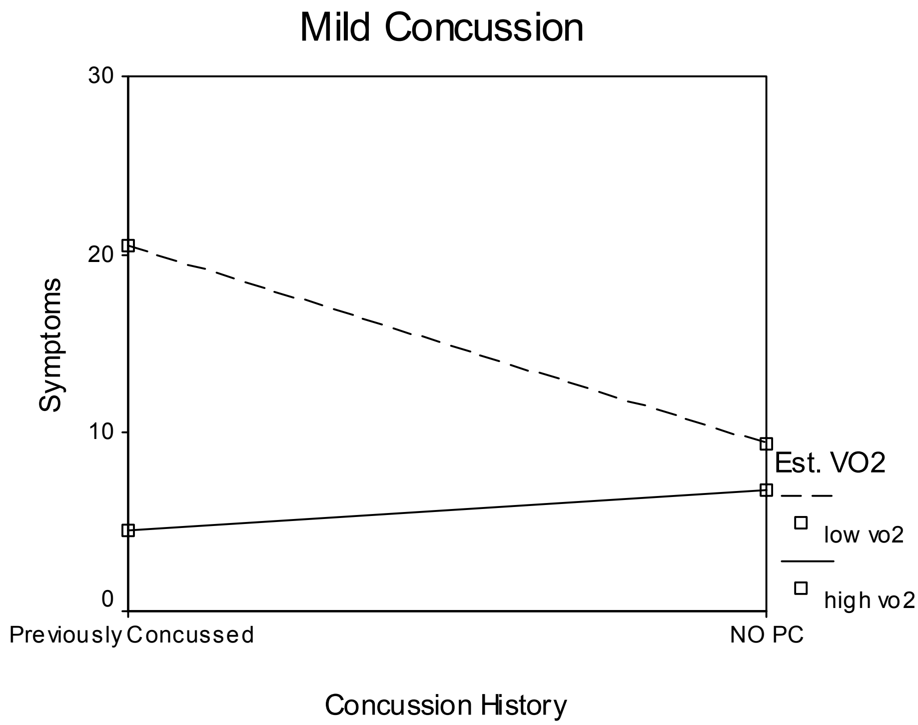

Figure 2. Interaction between estimated VO_2 max and previous concussion on total symptoms among mildly concussed athletes (*n*= 13)

The results also indicated a significant between subjects main effect for severity on total symptoms. Specifically, participants with severe concussions (*n*=7, *M*= 22.29, *SD*= 14.31) reported more symptoms than those with non-severe concussion (*n*=13, *M*=11.54, *SD*=10.63). A significant between subjects interaction for [estimated VO_2 max and previous concussion was also found (see Figure 3)].

Participants in the high estimated VO_2 max group who sustained a severe concussion (*n*= 2) reported fewer symptoms at baseline (*M*=9.5, *SD*=13.43) than athletes who incurred a severe concussion with a low (*n*= 5) estimated VO_2 max (*M*=18,

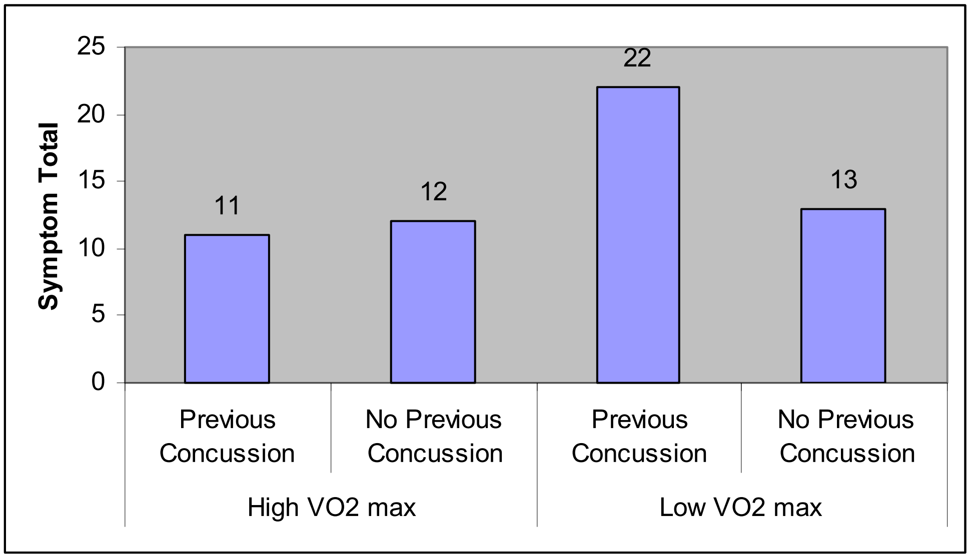

Figure 3. Symptom scores for previously concussed, high (n=2) and low (n=6) estimated VO_2 max participants

**p*≤ 0.05

SD=10.79). This trend was also apparent when comparing the high/low concussed groups that sustained a non-severe concussion. Concussed athletes high in estimated VO_2 max whom did not sustain a severe concussion (*n*= 5) reported fewer symptoms (*M*=7, *SD*=5.95) than those who had a low estimated VO_2 max (*n*= 8, *M*=11.8, *SD*=14.4).

Regarding concussion history there was an uncommon relationship between subjects who were high in estimated VO_2 max and reported previous concussion. Symptoms presented within the high estimated VO_2 max group were higher for those without having a prior concussion (*n*=5, *M*=10.2, *SD*=7.39) than those who had a previous concussion (*n*=2, *M*=1.5, *SD*=2.12). Subjects low in estimated VO_2 max and had a previous concussion (*n*=6) reported more symptoms (*M*=18.16, *SD*=13.24) at baseline than those who had no previous concussion (*n*= 7, *M*=10.85, *SD*=12.83).

Participants who sustained severe concussion (n=7) presented more symptoms (M= 22.2, SD=14.31) at 1-3 days post-injury than the non-severe group (n= 13, M=11.53, SD=10.62). Simply examining symptom reporting of severe concussion to non-severe concussion from baseline to 1-3 days post-injury showed an approximate mean increase of 7 symptom scores for severe, and an increase of only a mean of 1 symptom score for the non-severe injuries. This suggests that the more severe concussions present more symptoms within three days of injury than those concussions of lesser severity.

Participants high in estimated VO_2max (n=75) reported fewer symptoms (M=12.28, SD=13.76) than those low in estimated VO_2 max (n=83, M=16.9, SD=12.49) when mildly concussed. Examining severe concussions, the high estimated VO_2 max group (n=2) reported more symptoms (M=29, SD=18.38) than the low group (n=5, M=19.6, SD=13.8). This finding suggests that aerobic fitness only mitigates the effects of less severe concussions.

Participants with a history of previous concussion (n=8) reported more symptoms (M=19.25, SD=11.01) at 1-3 days post-injury than those who did not have any prior concussion (n=12, M=12.66, SD=13.66) in this study. Examining high and low estimated VO_2 max groups the group with the higher estimated VO_2 max (n=2) presented fewer symptoms at 1-3 days post-injury than those with low estimated VO_2 max (n=6).

Verbal Memory. The results of a 2 (estimated VO_2 max) x 2 (severity) x 2 (previous concussion) repeated measures ANOVA indicated no significant within subjects main effects for these factors on verbal memory (see Table 8). When examining estimated VO_2 max among participants with severe concussions, those high in estimated

VO_2 max (n=2, M= 0.83, SD= 0.21) scored higher in verbal memory than those low in estimated VO_2 max (n=5, M= 0.75, SD= 0.19).

Table 8

Results of a Repeated Measures ANOVA for estimated VO_2 max, Severity, and Previous Concussion on Verbal Memory Scores.

Factor	*Wilk's λ*	*F*	*Df*	*Error df*	*p*	η^2
Estimated VO_2 max	0.93	0.96	1	12	0.35	0.07
Severity	0.82	2.56	1	12	0.12	0.18
Previous Concussion	0.97	0.43	1	12	0.52	0.04

Visual Memory. The results of a 2 (estimated VO_2 max) x 2 (severity) x 2 (previous concussion) repeated measures ANOVA indicated no significant within subjects main effects for these factors on visual memory (see Table 9). These findings were not significant.

Table 9

Results of a Repeated Measures ANOVA for estimated VO_2 max, Severity, and Previous Concussion on Visual Memory Scores.

Factor	*Wilk's λ*	*F*	*Df*	*Error df*	*p*	η^2
Estimated VO_2 max	0.74	4.30	1	12	0.06	0.26
Severity	0.95	0.70	1	12	0.42	0.56
Previous Concussion	0.96	0.53	1	12	0.48	0.04

Motor Speed. The results of a 2 (estimated VO_2 max) x 2 (severity) x 2 (previous concussion) repeated measures ANOVA indicated a significant within subjects main effects for previous concussion on motor speed (see Table 10). An interaction between concussion severity and previous concussion was supported (*Wilk's* λ= 0.62, F [1, 12]= 7.39, p= .02, η^2= .38). Specifically, the non-severe group (n= 13) reported higher scores in motor speed than the severe group (n=7). This interaction is depicted in Figure 4.

Table 10

Results of a Repeated Measures ANOVA for estimated VO_2 max, Severity, and Previous Concussion on Motor Speed.

Factor	*Wilk's λ*	*F*	*Df*	*Error df*	*p*	η^2
Estimated VO_2 max	1.00	0.00	1	12	0.99	0.00
Severity	0.96	0.50	1	12	0.49	0.04
Previous Concussion	0.54	10.08	1	12	0.01	0.46

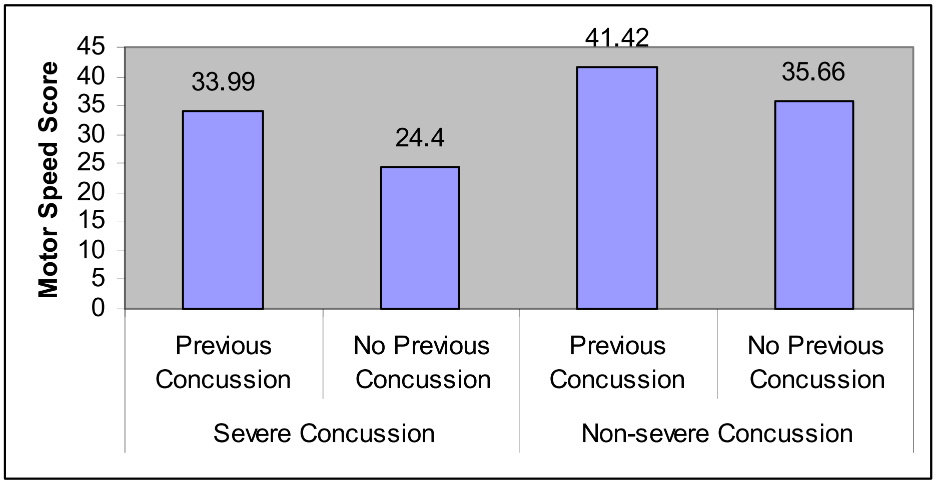

Figure 4. Motor speed scores for concussion severity and previous concussion

Reaction Time. The results of a 2 (estimated VO_2 max) x 2 (severity) x 2 (previous concussion) repeated measures ANOVA indicated no significant within or between subjects main effects for these factors on reaction time (see Table 11). Baseline scores of high estimated VO_2 max (M=0.52, SD=.05) were better than that of the low group. Also concussion severity did not differ when comparing the high and low estimated VO_2 max groups. Athletes with a previous concussion (n= 8) scored slightly worse than athletes who reported no previous concussion (n= 12) at 1-3 days post-injury. This may suggest the lingering effects of previous concussion with regards to reaction time. ImPACT data reported on module scores and symptom totals were not statistically significant.

Table 11

Results of a Repeated Measures ANOVA for estimated VO_2 max, Severity, and Previous Concussion on Reaction Time.

Factor	*Wilk's λ*	*F*	*Df*	*Error df*	*p*	η^2
Estimated VO_2 max	1.00	0.04	1	12	0.85	0.00
Severity	0.91	1.21	1	12	0.30	0.09
Previous Concussion	1.00	0.06	1	12	0.81	0.00

Hypothesis 2- Multiple post-concussion comparisons. These analyses were designed to examine changes in symptoms and modules among concussed participants from baseline to 1-3 days post-injury and to the second retest 6-9 days post-injury. Only seven concussed participants were retested through T2 up to 9 days post-injury (T2). A series of repeated measures ANOVAs comparing high and low estimated VO_2 max groups on post-concussion ImPACT module scores and symptoms from baseline to 1-3 days post-injury and 6-9 days post-injury indicated no significant results (see Table 12). Descriptive statistics of the ImPACT module scores and symptom totals for estimated VO_2 max up to 6-9 days post-injury can be found in Appendices F.

Table 12

Results of a Repeated Measures ANOVA for estimated VO_2 Max on ImPACT Modules and Symptom Totals From Baseline to Nine Days Post-Injury (n=7).

Estimated VO_2 Max	*Wilk's λ*	*F*	*df*	*Error df*	*p*	η^2
Verbal Memory	0.96	0.29	2	14	0.75	0.04
Visual Memory	0.90	0.80	2	14	0.47	0.10
Motor Speed	0.92	0.63	2	14	0.55	0.08
Reaction Time	0.85	1.23	2	14	0.32	0.15
Symptom Totals	0.65	3.75	2	14	0.65	0.06

Hypothesis 3- Concussed athletes with a high aerobic capacity, less severe concussion and no previous concussion history will have quicker recovery times than those with low aerobic capacity. Hypothesis 3 was examined using a 2 (estimated VO_2 max) x 2 (severity) x 2 (previous concussion) ANOVA for recovery time from concussion. Results supported a main effect for severity (see Table 16). Specifically, the more severe group (*n*= 7) recovered significantly slower than the less severe group (*n*= 13). The mean recovery time was three days faster for the high estimated VO_2 group (*n*= 5) than the low estimated VO_2 max group (*n*= 8) disregarding the severity of injury (see Figure 5), although this trend was not significant. Furthermore, those high in estimated VO_2 max who incurred a severe concussion (*n*= 2) recovered faster (*M*=9.50, *SD*=2.12) than the low estimated VO_2 max group (*n*= 5, *M*=11.6, *SD*= 4.43: see Figure 6), although again this trend was not significant.

Recovery curves of ImPACT module scores and symptom totals presented drop in neurocognitive performance and increased symptom totals within 9 days post-injury. Although non-significant, these data illustrate the delayed effects of concussion with regards to neurocognitive performance and presented symptoms in concussed athletes. These recovery curves are depicted in Figures 7-11.

Table 13

Analysis of Variance for Recovery Time from Concussion.

Factors	*SS*	*df*	*MS*	*F*	*p*	η^2
High/Low estimated VO_2 max	25.81	1	25.81	2.09	0.17	0.15
Previous Concussion	49.28	1	49.28	3.99	0.07	0.25
Severity	149.26	1	149.26	12.01	0.01	0.50

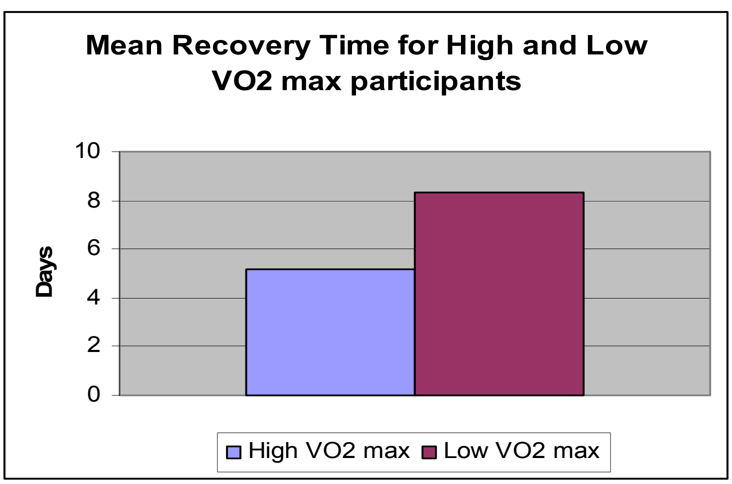

Figure 5. Mean recovery time for participants with high (*n*=7) and low (*n*=13) estimated VO_2 max values incurring non-severe concussion.

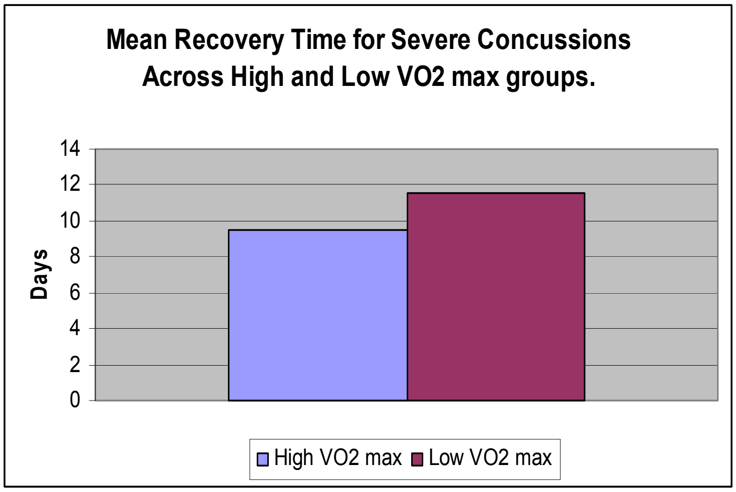

Figure 6. Mean recovery time for high (*n*=2) and low (*n*=5) estimated VO_2 max participants incurring severe concussion.

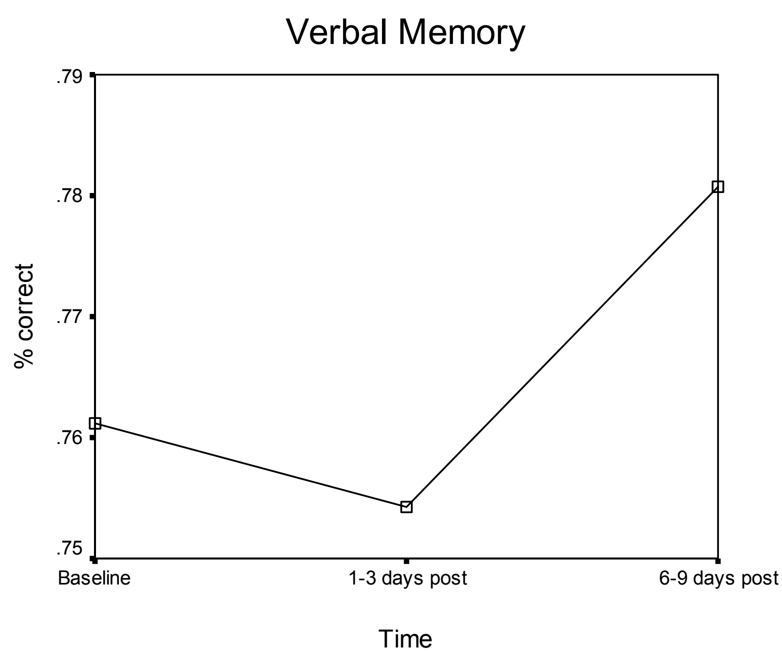

Figure 7. Recovery curve for verbal memory in concussed participants (*n*= 7)

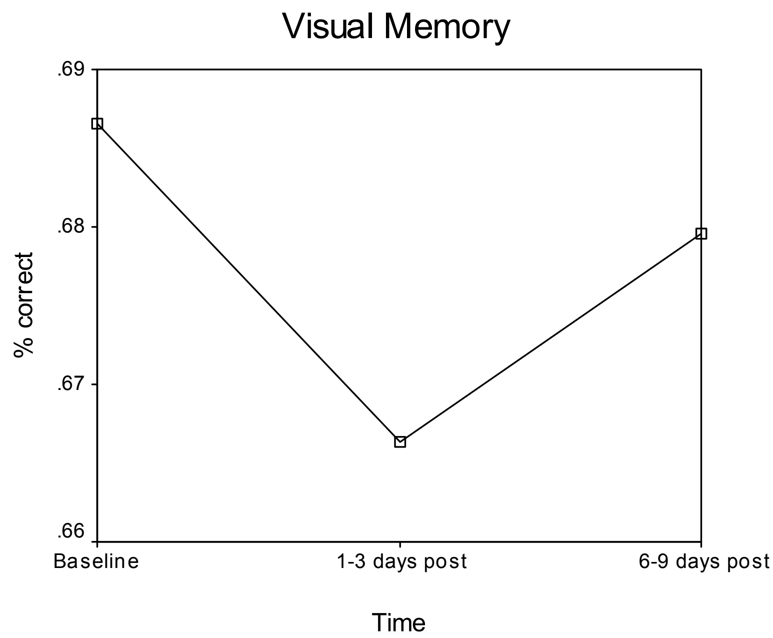

Figure 8. Recovery curve for visual memory in concussed participants (*n*= 7)

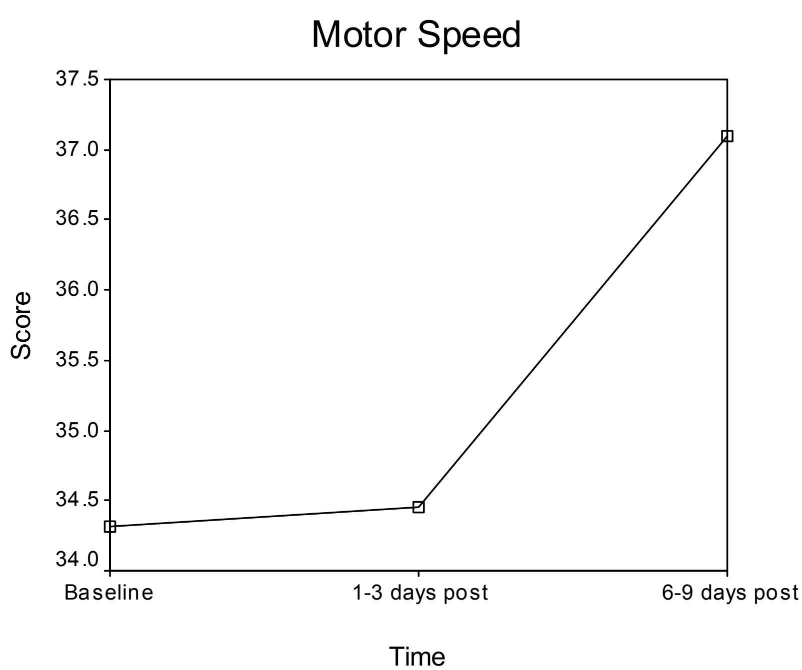

Figure 9. Recovery curve for motor speed in concussed participants (*n*= 7)

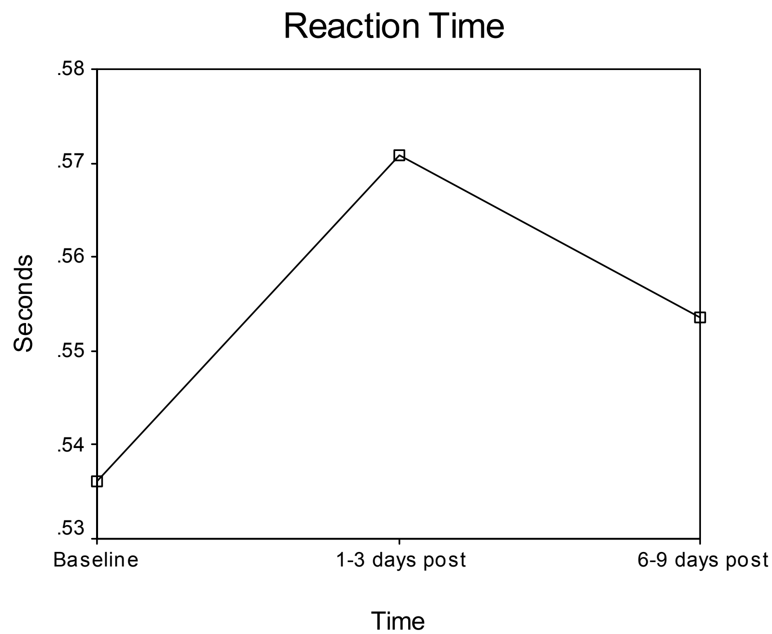

Figure 10. Recovery curve for reaction time in concussed participants (*n*= 7)

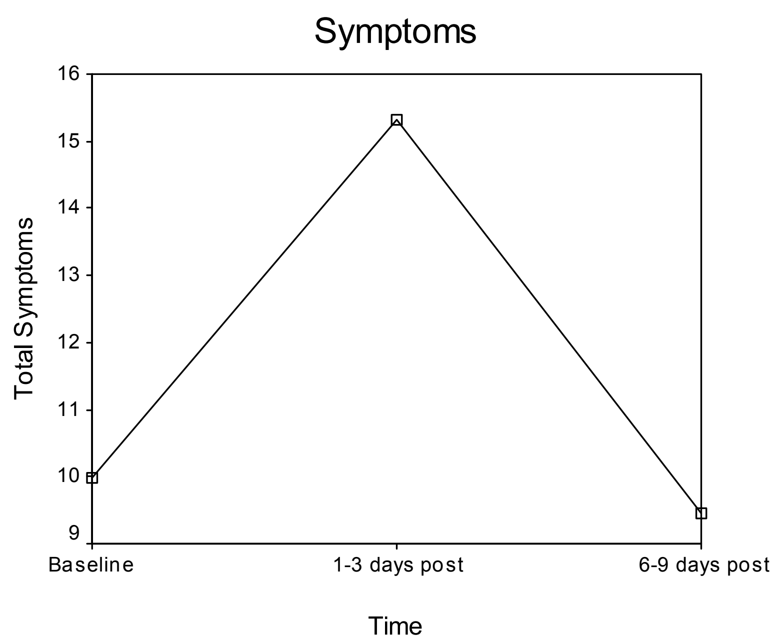

Figure 11. Recovery curve for symptoms in concussed participants (*n*= 7)

Exploratory Question 1: What Factors Best Predicted Concussion Risk?

A logistic regression (LR) using an enter method was used to determine which factors in this study best predicted concussion. The factors included in the LR were age, height, weight, years experience, handedness, educational grade, previous concussion, estimated VO_2 max, practice exposures, and game exposures. The overall LR model was significant (χ^2[10, 158]= 19.29, p= .04, *Nagelkerke's* R^2= 0.22). The results indicated that only practice exposures (p= .05) and game exposures (p= .03) were significant predictors of concussion. The OR associated with practice exposures was 1.10 (95% CI= 1.02-1.18). However, the OR associated with competition exposures was 0.80 (95% CI= 0.65-0.99). This finding suggests that practice exposures were a risk factor, whereas competition exposures were a protective factor for concussion.

Post Hoc Analyses: 'Bell Ringers' and Post-season Concussion Symptoms

At the end of the season all participants who had not been concussed completed a brief questionnaire pertaining to whether or not they had their 'bell rung', and if so, to indicate how many 'bell ringers' they had. The participants also reported any lingering post-season concussion-related symptoms.

Surprisingly, 28% of these participants reported having their 'bell rung' (n= 38). This finding suggests that many potential concussions (i.e., 'bell ringers') were not reported by athletes or recorded by sports medical staffs.

A logistic regression was used to determine which factors best predicted bell-ringers and post-season concussion symptoms. The overall LR model was significant (χ^2[10, 158]= 28.38, p= .02, *Nagelkerke's* R^2= 0.27). These results indicated that only practice exposures (p=.04) and game exposures (p= .01) were significant predictors of concussion. The OR associated with practice exposures was 1.10 (95% CI= 1.10-1.17) and the OR associated with game exposures was 1.20 (95% CI= 1.02-1.33). This finding suggests that both factors were significant, though low magnitude risk factors for 'bell ringers.'

CHAPTER V

DISCUSSION

Introduction

The factors affecting concussion risk, severity and recovery are largely unknown. The current study suggests that previous concussion and aerobic fitness might play a role in concussion outcomes. A discussion of these and other findings is presented below. Implications of the current study's findings for sport medicine professionals, coaches and athletes are presented. Limitations of the current study and suggestions for future research are also discussed.

General Discussion of Results

The results of the current study indicated that athletes who had a history of previous concussion were at a higher risk for incurring another concussion than those who did not have a history of this injury. Previously concussed athletes who were classified as high in estimated VO_2 max for this study presented fewer symptoms when mildly concussed at three days post-injury than those low in estimated VO_2 max. Aerobic fitness was also associated with a reduction in the symptoms of mild concussion, but was not related to symptoms in severe concussions.

A non-significant trend in the data suggested that athletes high in estimated VO_2 max did experience faster recovery times than those who were low in estimated VO_2 max. As expected, athletes who experienced more severe concussions reported longer recovery times than those with less severe concussions. Finally, a post-hoc analysis indicated that concussion appear to be underreported by high school football players.

Concussion Rates

Participants with a learning disability, hyperactive disorder (i.e., ADD/ADHD), previous or existing physical brain impairment, and/or substance abuse problems were excluded from the study due to the potential confounding effect of these factors on neuropsychological test scores, as reported by Collins et al. (2003). Over the course of the data collection period 13% (*n*=20) of participants incurred a concussion, moreover, 35% (*n*=7) sustained a second concussion during the season. The concussion rates in this study were 2.3 per 1000 exposures and 2.66 per 100 participants. These rates are lower than previous findings by Powell and Barber-Foss (1999) who reported a concussion incidence rate of 3.66 per 100 high school football player. Differences in exposures between the current and other studies may have accounted for this finding. To be included as an exposure in the Powell and Barber-Foss study, athletes had to be involved in potential physical contact either in a practice or game. In the current study exposures included any participation in a practice or game, even if it was brief in nature. Therefore, the current study's rates may reflect a slightly lower incidence of concussion due to an inflated number of exposures per player.

Aerobic Fitness and Recovery

A non-significant trend in the current study suggested a relationship between aerobic fitness and recovery time in mild concussions. Specifically, athletes who had a high aerobic fitness level experienced faster recovery times than those who were not as aerobically fit. According to Collins et al. (2003) the average recovery time for concussed high school football players is approximately ten days. The concussed low aerobic fitness group in this study followed this trend with a recovery time ranging from

8 to 10 days post injury. However, the concussed high aerobic fitness group had a recovery time of approximately 5 days post injury. This three to five day difference in recovery time suggests that the benefits (i.e., blood vessel elasticity, increased stroke volume) of being more aerobically fit as described in Dustmann et al. (1984), might enhance recovery of the brain after a concussion. However, this trend was not present in severe concussions. Severely concussed athletes had longer recovery times regardless of aerobic fitness levels. This may indicate that aerobic fitness is a protective factor only in mild concussions. This evidence partially supports the hypothesized relationship regarding recovery time and aerobic fitness. This trend warrants further investigation and identifies aerobic fitness in high school athletes as a possible mitigating factor in recovery from mild concussions.

Symptom and Neurocognitive Effects

Symptoms reported at the initial time of injury and throughout the recovery time of a concussed high school football player are integral to decisions and assessments made by the medical staff. Symptom reporting is a subjective method of relying on the athlete to disclose any effects or symptoms he might be experiencing due to injury. This study examined symptom reporting in high and low aerobically fit concussed athletes who incurred a concussion which was mild or severe in nature. Non-significant trends indicated that those high in aerobic fitness reported fewer symptoms than athletes low in aerobic fitness from the time of initial injury throughout recovery. These trends also pointed to higher composite scores on neurocognitive computerized testing (ImPACT) protocols in the more aerobically fit athlete. Specifically, a statistically significant trend indicated higher scores in motor speed in high estimated VO_2 max athletes. However all other ImPACT modules experienced a decline in both high and low estimated VO_2 max groups.

This drop was profoundly apparent approximately three days post-injury, which is consistent with findings from Iverson et al. (2004), who described a similar drop in symptoms reported and overall cognitive function at three days post-injury. Additional evidence of the delayed effects of concussion was also reported in Lovell et al. (2003), who reported a drop in ImPACT scores (i.e., verbal memory, visual memory, motor speed, and reaction time) at 36 hours post-injury, with improved performance following at four days post-injury. These data are consistent with the recovery curves reported in the current study. However, although not significant, athletes who were higher in estimated VO_2 max experienced a more subtle drop in cognitive functioning and symptom reporting than those who were low in estimated VO_2 max. Due to the fact that this trend is non-significant, further investigation is warranted.

Concussion History

The effects of concussion appear to be cumulative in nature (Iverson et al., 2004). Therefore, and as indicated in the current study, athletes with a history of concussion are at a higher risk for repeat injury than those who have not incurred any previous concussions. This study indirectly examined the cumulative effects of concussion, and found that high school football players who had a previous history of concussion, regardless of their aerobic condition, presented more symptoms three days post-injury than those with no history.

Concussion Severity

The severity of concussions in this study was assessed by initial examination of on-field symptoms reported at the time of injury by sport medicine staff as per the protocol from Iverson et al. (2004). Results of the current study suggested that athletes with severe concussions reported more symptoms at three-day post injury than those with mild concussions. The current study also reported non-significant trends indicating that concussion recovery was longer and ImPACT scores lower among severe compared to mild concussed groups. These findings suggest that on-field initial markers of severity were accurate in assessing concussion severity, and should continue to be used by sport medicine professionals and coaches. The current study also found that concussion severity was not influenced by any risk or protective variables (i.e., aerobic fitness, concussion history).

Predicting Concussion

An exploratory question examined which factors in the current study predicted concussion. The only significant predictors were practice exposures, which was a risk factor, and game exposures, which was a protective factor. The latter finding is contrary to Zemper (2003), who found that concussions were more likely in games than practices. The current study's findings may reflect the fact that several of the teams exposed their athletes to constant high physical contact in practice, which is not typically the case. Moreover, the game exposures in the current study were not time sensitive and were recorded even if a player made only a brief appearance on the field. Consistent exposure definitions would mitigate these equivocal findings in future studies.

Underreporting of Concussion

A post-hoc analysis concerning the phenomena of “bell-ringers” (i.e., unreported concussions) was examined. Twenty-eight percent (n= 44) of participants indicated on a post-season questionnaire that they had had their ‘bell rung’ and experienced concussive symptoms. This finding supports the contention of McCrea et al. (2004) concerning the underreporting of symptoms by high school athletes. This phenomenon of athletes failing to report their symptoms to medical staffs and coaches may be directly related to the consequences of not playing and the masculine stereotypes among football players. Also, the subtle symptoms that were reported (i.e., headaches, nausea, dizziness) need to be given more attention by the medical staff due to the fact that many athletes believe that these mild symptoms are not serious enough to warrant reporting. This is concurrent with the findings of Field et al. (2003) regarding the inaccuracy of self-reported symptoms in high school athletes. An argument could also be made that the issue may be lack of knowledge about the relevance of their symptoms rather than lack of communication on the part of athletes.

Implications of Findings

Coaches and trainers need to be aware of each athlete’s concussion history, as it is a significant risk factor for subsequent concussions. Concussion history should become a standard part of the preseason physical exam, and be considered as a risk factor for further injury. Concussion symptom reporting may also be useful in the preseason physical. Ideally, all athletes would be given a baseline assessment such as ImPACT, but this is costly and difficult for high schools to justify. Educational programs need to emphasize that a mild concussion can be severe or non-severe, and that each athlete will recover according to his own individualized physiological nature.

This study supported the potential importance of high school football players' fitness level in regard to improving concussion outcomes. Surprisingly, very few participants in the current study were high in aerobic fitness using standard criteria (p.77), (ACSM 2002). It is common to assume that playing football and participating in practice and/or games will keep an athlete in high aerobic condition. However, it more likely that fitness levels are position specific. Regardless, coaches and trainers should focus more on aerobic fitness for all positions.

Coaches should be aware that excessive contact throughout a practice week can subject athletes to a high risk of concussion. Exposure to concussion and/or concussive blows can be reduced by teaching proper techniques and using dummy pads for light contact while in preparation for the upcoming competition. High school athletic departments need to make sure that they are taking every advantage of keeping the safety of their high school football players as a top priority by investing in proper equipment to avoid unnecessary full contact on a regular basis.

Team medical staffs and coaches need to be aware of new information and findings regarding concussion. It is imperative that every high school football team has a set policy to manage concussion that is consistent with every player, no matter how integral that player is to the team's success. On field severity of concussion reporting should be part of that policy, as it was efficacious in predicting concussion severity in the current study. In the event that a player fails to report a concussion or is trying to hide their symptoms, so that they will not be removed from competition, objective measures should be implemented by decision-making bodies (i.e., school boards, coaches, ATC's) to ensure that a safe, up-to-date protocol for managing concussion is in place. If neurological testing is used, then athletes need to be monitored during baseline testing to ensure that malinger and sabotage testing are avoided prevented. Newer versions of ImPACT and other programs now incorporate a lie scale to locate these problem cases. Reports on each athlete should be reviewed in a timely manner to assess how thorough each test was taken. Education for those who make return-to-play decisions is strongly recommended to ensure that coaches, trainers, and medical professionals are current with new findings and literature regarding concussion in high school football.

Limitations

There are several limitations of this study and methods used to collect data. The study was limited in sample size due to the fact that few concussions occurred among the participant pool. A larger sample size could possibly help to illuminate the non-significant trends that were found regarding the aerobic fitness on the severity, risk, and recovery on concussed high school athletes.

The post-hoc analysis indicated a limitation that many concussions are unreported by medical staff due to the fact that players do not report symptoms. In the current study, potentially as many as 60 players might have been concussed, but only 20 were recorded. Lastly, concussed and non-concussed participants who did not take their baseline ImPACT testing seriously, had to be excluded from the study. This may present a problem in managing concussion when using a pre and post injury test assessment such as ImPACT. It should be noted that this is not uncommon among high school athletes.

Suggestions for Future Research

Future research efforts examining the factors that may contribute to concussion should include more participants than this study. Also, newer versions of ImPACT testing needs to be used, and baseline test need to be more closely monitored for athlete sabotage. It is imperative to record valid reliable baseline data in order to track recovery with computerized testing protocols.

Lastly, future research needs to address the phenomena of athletes failing to report symptoms. Educational efforts such as informational meetings, conferences, and/or brochures concerning the dangers of unreported concussion need to be conducted with all governing bodies that monitor the safety of high school football players. These efforts could keep players on the field and possibly ensure a healthy, fully functional life as an adult.

REFERENCES

American College of Sports Medicine. (2000).Guidelines for exercise testing and prescription.

Aubry, M., Cantu, R., Dvorak, J., Graf-Baumann, T., & Johnston, K., et al. (2002). Summary and agreement statement of the first international conference on concussion in sport, Vienna 2001. *The Physician and Sportsmedicine, 30,* 57-63.

Bailes, J., & Cantu, R. (2001). Head injury in athletes. *Neurosurgery, 48,* 26-46.

Biagus, K. V., Grundl, P. D., Kochanek, P. M., Schiding, J. K., & Nemoto, E. M. (1996). Posttraumatic hyperemia in immature, nature, and aged rats: Autoradiographic determination of cerebral blood flow. *Journal of Neurotrauma*, *13*, 189-200.

Black, J. E., Isaacs, K. R., Anderson, B. J., Alcantara, A. A., & Greenough, W. T. (1990). Learning causes synaptogensis, whereas motor activity causes angiogenesis in cerebellar cortex of adult rats. *Proceedings of the National Academy of Sciences, USA, 87,* 5568-5572.

Cantu, R. C. (2001). Posttraumatic retrograde and anterograde amnesia: Pathophysiology and implications in grading and safe return to play. *Journal of Athletic Training, 36,* 244-248.

Cantu, R. C. (1992). Cerebral concussion in sport. *Sports Medicine, 14,* 64-74.

Collins, M. W., Grindel, S. H., Lovell, M. R., Dede, D. E., & Moser, D. J., et al. (1999). Relationship between concussion and neuropsychological performance in college football players. *Journal of the American Medical Association, 282 ,* 964-970.

Collins, M. W., Field, M. F., Lovell, M. R., Iverson, G., & Johnston, K. M., et al. (2003). Relationship between postconcussion headache and neuropsychological test performance in high school athletes. *American Journal of Sport Medicine, 31,* 168-173.

Collins, M., Iverson, G., Lovell, M., McKeag, D., & Norwig, M. A., et al. (2003). On-field predictors of neuropsychological and symptom deficit following sports-related concussion. *Clinical Journal of Sport Medicine, 13,* 222-229.

Collins, M. W., Stump, J., & Lovell, M. R. (2004). New developments in the management of sports concussion. *Current Opinion in Orthopaedics, 15,* 100-107.

DeWitt, D. S., & Prough, D. S. (2003). Traumatic cerebral vascular injury: The effects of concussive brain injury on the cerebral vasculature. *Journal of Neurotrauma, 20,* 795-825.

Dustman, R. E., Emmerson, R., & Shearer, D. (1994). Physical activity, age, and cognitive-neuropsychological function. *Journal of Aging and Physical Activity, 2,* 143-181.

Dustman, R E., Ruhling, R. O., Russell, E. M., Shearer, D. E., & Bonekat, W. H., et al. (1984). Aerobic exercise training and improved neuropsychological function of older individuals. *Neurobiology of Aging, 5*, 35-42.

Field, M., Collins, M. W., Lovell, M., & Maroon, J. (2003). Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *Journal of Pediatrics, 142*, 546-553.

Francis, K. (1990). A new single-stage step test for the clinical assessment of maximal oxygen consumption. *Physical Therapy, 70,* 734-738.

Francis, K., & Brasher, J. (1992). A height-adjusted step test for predicting maximal oxygen consumption in males. *The Journal of Sports Medicine and Physical Fitness, 32,* 282-287.

Grundl, P. D., Biagas, K. V., Kochanek, P. M., Schiding, J. K., & Nemoto, E. M. (1994). Early cerebrovascular response to head injury in immature and mature rats. *Journal of Neurotrauma*, *11,* 135-148.

Guskiewicz, K., Weaver, N., Padua, D., & Garrett, W. (2000). Epidemiology of concussion in collegiate and high school football players. *The American Journal of Sports Medicine*, *28,* 643-649.

Iverson, G. L., Gaetz, M., Lovell, M. R., & Collins, M. W. (2004). Cumulative effects of concussion in amateur athletes. *Brain Injury, 18,* 433-443.

Iverson, G. L., Lovell, M., & Collins, M. W. (2003). Interpreting change on ImPact following sport concussion. *The Clinical Neuropsychologist , 17,* 460-467.

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., & McAuley, E., et al. (1999). Aging, fitness, and neurocognitive function. *Nature, 400,* 418-419.

Lovell, M. R., Collins, M. W., Iverson, G., Johnston, K. M., & Bradley, J. P. (2004). Grade 1 or "Ding" concussions in high school athletes. *The American Journal of Sports Medicine, 32,* 47-54.

Lovell, M. R., Collins, M. W., Iverson, G. L., Field, M., & Maroon, J. C., et al. (2003). Recovery from mild concussion in high school athletes. *Journal of Neurosurgery, 98*, 296-301.

Lovell, M. R., Iverson, G. L., Collins, M. W., McKeag, D., & Maroon, J. C. (1999). Does loss of consciousness predict neuropsychological decrements after concussion? *Clinical Journal of Sport Medicine, 9,* 193-198.

Lovell, M., & Collins, M. (1998). Neuropsychological assessment of the college football player. *Journal of Head Trauma and Rehabilitation, 13,* 9-26.

McCrea, M., Hammeke, T., Olsen, G., Leo, P., & Guskiewicz, K. (2004). Unreported concussion in high school football players. *Clinical Journal of Sports Medicine, 14,* 13-17.

Marchal, G., Rioux, P., Peit-Taboue, M. C., Sette, G., Travere, J. M., et al. (1992). Regional cerebral oxygen consumption, blood flow, and blood volume in healthy human aging. *Archives of Neurology*, *49,* 1013-1020.

Maroon, J. C., Lovell, M. R., Norwig, J., Podell, K., & Powell, J. W., et al. (2000). Cerebral concussion in athletes: Evaluation and neuropsychological testing. *Neurosurgery, 47,* 659-672.

Powell, J. W., & Barber-Foss, K. D. (1999). Traumatic brain injury in high school athletes. *Journal of the American Medical Association, 282,* 958-963.

Sramek, J. G., & Byrne, R. W. (1998). Managing sports-related concussion. *Your Patient & Fitness, 12,* 31-34.

Zemper, E D. (2003). A two-year prospective study of cerebral concussion in American football. *Research in Sports Medicine*, *11, 1*57-172.

APPENDICES

APPENDIX A

UPMC Sideline Assessment Card

UPMC Sports Medicine

Sports Concussion Program

Part of University of Pittsburgh Medical Center

Concussion Signs and Symptoms Evaluation

Signs observed by staff

- appears to be dazed or stunned
- is confused about assignment
- forgets plays
- is unsure of game, score, or opponent
- moves clumsily
- answers questions slowly
- loses consciousness ***(even temporarily)***
- shows behavior or personality change
- forgets events prior to hit ***(retrograde)***
- forgets events after hit ***(anterograde)***

Symptoms reported by athlete

- headache
- nausea
- balance problems or dizziness
- double or fuzzy vision
- sensitivity to light or noise
- feeling sluggish
- feeling "foggy"
- change in sleep pattern
- concentration or memory problems

Symptoms may worsen with exertion.
Athlete should not return to play until symptom-free.

For more information

800-533-UPMC (8762)

APPENDIX A CONTINUED

On-field Cognitive Testing

Orientation

Ask the athlete the following questions.

What stadium is this? What month is it?

What city is this? What day is it?

Who is the opposing team?

Anterograde amnesia

Ask the athlete to repeat the following words.

Girl, dog, green

Retrograde amnesia

Ask the athlete the following questions.

What happened in the prior quarter/period?

What do you remember just prior to the hit?

What was the score of the game prior to the hit?

Do you remember the hit?

Concentration

Ask the athlete to do the following.

Repeat the days of the week backward (starting with today).

Repeat these numbers backward:

63 ***(36 is correct)*** 419 ***(914 is correct)***

Word list memory

Ask the athlete to repeat the three words from earlier. (Girl, dog, green)

Any failure should be considered abnormal.
Consult a physician following a suspected concussion.

APPENDIX B

Player Weekly Attendance

School: ______________________________

Trainer: ______________________________

Week of: _____________________________

Number of days of contact:______________

Players who missed practice/games:

Name	Day/s Missed
1. _________________________	___________________
2. _________________________	___________________
3. _________________________	___________________
4. _________________________	___________________
5. _________________________	___________________
6. _________________________	___________________
7. _________________________	___________________
8. _________________________	___________________
9. _________________________	___________________
10. _________________________	___________________

APPENDIX C

PLAYER INFORMATION SHEET

Age: _________

Height: _________

Weight: _________

Position: _________

Returning Letter-winner (yes/no): ____________

APPENDIX D

Equation for Three-minute Step Test

Ages 6-17: VO2 max = 103.42 – (1.588 x 15 second recovery heart rate)

APPENDIX E

End of Season Questionnaire

NAME:_________________________________

1. Where you **retested on the computer for a concussion** this season? ***(circle one)***

Yes / No

If you answered YES to Item #1- STOP- YOU ARE DONE.

I f you answered NO to Item #1- GO TO THE NEXT ITEM (#2).

2. Did you have your **"bell rung" (i.e., a concussion)** while playing this season? ***(circle one)***

Yes / No

3. If so, how many times did this happen?***(circle only one number)***

1 2 3 4 5 6 7 8 9 10 11+

4. For each time that you had your **"bell rung" (i.e., concussion)** indicate which, if any of the following **symptoms** you had: ***(check all that apply)***

- ○ Temporary loss of consciousness
- ○ Headache
- ○ Dizziness
- ○ Balance problems
- ○ Trouble Remembering Plays or Events
- ○ Visual Changes
- ○ Confusion
- ○ Disorientation
- ○ Personality Change
- ○ Fatigue
- ○ Trouble falling asleep
- ○ Drowsiness
- ○ Hard to concentrate
- ○ Irritable or mad
- ○ Upset stomach
- ○ Vomiting
- ○ Loud noise hurt your ears
- ○ Bright lights hurt your eyes
- ○ Slept more than normal
- ○ Slept less than normal
- ○ Sadness
- ○ Nervousness
- ○ Numbness or Tingling
- ○ Felt slowed down
- ○ Felt mentally foggy

APPENDIX F

Descriptive Statistics for Estimated VO_2 Max on ImPACT Module Scores and Symptom Totals From Baseline to Nine Days Post-Injury.

	Estimated VO_2 Max											
	Baseline				Three Days Post-Injury				Nine Days Post-Injury			
	High		Low		High		Low		High		Low	
Module	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Verbal Memory	0.78	0.09	0.75	0.13	0.75	0.16	0.76	0.12	0.76	0.22	0.80	0.10
Visual Memory	0.75	0.15	0.63	0.14	0.67	0.21	0.66	0.11	0.69	0.24	0.67	0.10
Motor Speed*	35.35	10.41	33.28	6.30	35.64	11.91	33.27	6.75	37.00	14.87	37.20	5.74
Reaction Time	0.52	0.05	0.56	0.10	0.55	0.06	0.59	0.19	0.59	0.23	0.52	0.05
Total Symptoms	7.66	8.14	12.27	10.21	13.17	14.86	17.45	13.62	8.83	14.96	10.09	6.50

*$p \leq 0.05$

APPENDIX G

University Committee for the Protection of Human Subjects in Research University of New Orleans

Campus Correspondence

Robert Elbin, III, PI
Anthony Kontos, Faculty advisor
Human Performance and Health Promotions
109 HPC

8/11/2004

RE: The relationship between aerobic fitness and concussion risk, severity, and recovery in high school football

IRB# 04AUG04

The IRB has reviewed your proposed research and is requiring the following clarifications to your proposed study. Please revise the language of the parental consent and child assent forms to be appropriate for a less sophisticated reading level (e.g., 6th grade level). Please submit the revised consent to me within the next 15 days.

All other components of the planned research are compliant with the University of New Orleans and federal guidelines.

Please remember that approval is only valid for one year from the approval date. Any changes to the procedures or protocols must be reviewed and approved by the IRB prior to implementation. Use the IRB number listed on this letter in all future correspondence regarding this proposal.

If an adverse, unforeseen event occurs (e.g., physical, social, or emotional harm), you are required to inform the IRB as soon as possible after the event.

Best of luck with your project!
Sincerely,

Laura Scaramella

Laura Scaramella
Chair, University Committee for the Protection of Human Subjects in Research

VITA

Robert James Elbin III (R.J.) was raised in Bedford, Pennsylvania. R.J. attended Delgado Community College in New Orleans, Louisiana in the spring of 1998 where he was a member of the varsity baseball team. One year later, R.J. received his Associates degree in Business from Delgado. R.J. was accepted at the University of New Orleans where he completed his undergraduate work and earned his Bachelors of Science degree in Healthcare Management. He was also a member of the men's varsity baseball team at UNO. In the fall of 2002, R.J. was accepted into the Human Performance and Health Promotion graduate program at the University of New Orleans. During his graduate work R.J. has focused on the psycho-physiological aspects of sport and sport injury which has lead him to pursue such research interests as head injury and psychological effects of injury in sport. Upon graduation, R.J. will apply for an assistantship position in a doctoral program to continue his research interests.