CHAPTER 2

AEROBIC FITNESS AND CONCUSSION OUTCOMES IN HIGH SCHOOL FOOTBALL

Anthony P. Kontos[1]; Robert J. Elbin III[1], Michael W. Collins[2]

[1]*Behavioral Performance Lab, Department of Human Performance and Health Promotion University of New Orleans 2005;akontos@uno.edu*

[2]*Sports Concussion Program, Sports Medicine Center University of Pittsburgh Medical Center*

Abstract: The purpose of this study was to provide an initial examination of the effects of aerobic fitness and concussion history on concussion risk, symptoms and neurocognitive impairment, and recovery in high school football players. Participants (*N*=158) completed estimated VO2 max and baseline neurocognitive tests (i.e., ImPACT). Concussed athletes completed ImPACT 24-72 hours post-injury, and again every 48-72 hours until they were asymptomatic or returned to baseline levels. Twenty-three players incurred concussions. The concussion incidence rate was 2.63/1000 exposures. Initial on-field assessments of post-traumatic amnesia (PTA) corresponded to post-concussion symptoms and neurocognitive declines on ImPACT. Previously concussed athletes were 3.71 times more likely to be concussed than those with no concussion history. A trend indicated that athletes low in aerobic fitness might be at greater risk (*OR*= 1.80) for concussion than those high in aerobic fitness. Aerobic fitness and history of concussion were not related to concussion symptoms and neurocognitive impairment. Athletes with no history of concussion and those initially evaluated with PTA recovered faster than those with a history of concussion and those initially evaluated without PTA. A trend suggested that high aerobic fitness might be related to faster recovery times.

Keywords: concussion, aerobic fitness, high school football

1. INTRODUCTION

1.1. Statement of the Problem

Two high school football players converge 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 unbeknownst to the medical staff. 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 confusion and headache, and has trouble recalling events prior to his injury. The symptoms displayed by this athlete indicate that he has sustained a 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 and location of the injury sustained by each player was the same; however, they experienced different outcomes. Surprisingly, researchers know very little about which factors might influence concussion risk, symptoms and neurocognitive impairment, or recovery in cases such as these.

A concussion is defined by the First International Conference on Concussion in Sport as a "complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (Aubry, Cantu, Dvorak, Graf-Baumann, & Johnston, 2002). A concussion 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 concussion symptoms and neurocognitive decrements to some factors such as age of the athlete (Field, Collins, Lovell, & Maroon, 2003). However, researchers are just beginning to uncover the myriad of factors that might influence concussion. Understanding the factors that influence concussion can help medical staff, coaches, parents and athletes in making better decisions regarding the concussion prevention, management and recovery.

One factor that has been examined by researchers is concussion history. Athletes who have sustained a previous concussion have an increased risk of subsequent concussions (Zemper, 2003). Research (Zemper, 2003) also suggests that concussions can lead to long term decrements and symptoms, and increased risk for concussions with more symptoms and neurocognitive impairment. Multiple concussions may also predispose an athlete to second-impact syndrome (Iverson, Gaetz, Lovell & Collins, 2004). Consequently, information regarding concussion history is now included on many 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 (governing body where the current study was conducted) 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.

Studies (e.g., Lovell & Collins, 1998) have consistently demonstrated that concussed athletes experience different recovery times, but have only recently begun to examine which factors might contribute to recovery. Another potential factor that might influence recovery and other concussion outcomes is aerobic fitness. Aerobic fitness significantly improves neuropsychological performance in older individuals with neurocognitive decrements (Dustman, Ruhling, Russell, Shearer, & Bonekat, et al. 1984). These decrements and symptoms as reported in Dustman et al. (1984) are similar to the symptoms reported by concussed football players by Collins, Iverson, Lovell, McKeag and Norwig (2003). Therefore, the level of aerobic fitness may influence concussion risk, symptoms and neurocognitive impairment, and recovery via its effects on the brain and subsequent neurocognitive performance.

1.2. Concussion Statistics in High School Football

There are an estimated 43,000 concussions annually in high school football (Zemper, 2003). The concussion incidence rate for high school football is 3.71 concussions per 100 players, which is much higher than any other American high school sport. High school football accounts for 63% of all concussions reported by Powell and Barber-Foss (1999). Research indicates that one out of every five high school football players will experience a concussion during their playing career (Sramek, 1998). These numbers suggest that developing a better understanding of concussion and factors that affect it among high school athletes is warranted. However, these and other concussion statistics must first be clarified.

There has been some discrepancy in statistics and methodologies in the concussion literature. One methodology consists of examining concussions per 1000 exposures. Exposures are typically defined as one athlete being exposed in one game or practice in which there is contact, or the possibility of being injured. Some studies also include as exposures practices where there is no contact such as "walkthroughs" or "pre-game" events. These practices are usually held without pads, are non-contact in nature, and result in lower concussion rates. The resulting findings can then underestimate the incidence of concussion. 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 each athlete. A study by Zemper (2003), for example, reported that the incidence rate of concussion at the high school level was 3.71 concussions per 100 players. The rate for college football players in the same study was 4.21 concussions per 100 team members. These rates seem to suggest that college football players are at greater risk for concussion than high school players. However, the risk may actually be quite similar, as college football typically involves more practices and games (i.e., exposures) than high school football. Therefore, the exposure level of college athletes is different than for high school athletes. When exposures are not taken into consideration, the statistics can be misleading.

1.3. Concussion Testing

Traditionally, the benchmark symptom of a concussion was loss of consciousness (LOC: Lovell, Iverson, Collins, McKeag, & Maroon, 1999). Many of the over 30 concussion guidelines currently in use rely on LOC as an indicator of concussion, are anecdotal in nature, and lack empirical support. Loss of consciousness is an important symptom of a concussion, but studies have questioned the validity of LOC alone in determining a concussion (e.g., Lovell, Collins, Iverson, Field, & Maroon et al., 2003). Other symptoms, particularly PTA, are important to consider when assessing concussion. Concussions often involve "hidden" or subtle symptoms such as consistent headache, dizziness, brief disorientation, and/or nausea (Lovell et al., 2003). These symptoms are difficult to assess as they are mostly 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 concussion unless it is self-reported. Athletes' self-reported symptoms may also be inaccurate or minimized because of their desire (or pressure) to return to play (Kontos, Russo, & Collins, 2002). Studies have suggested that educational programs are needed to inform athletes, parents, coaches and medical staffs of the signs and symptoms of concussion and potential risks of unreported injuries (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004).

In summary, clinical on-field guidelines based on LOC have fallen short of identifying the lasting effects of a concussion beyond the initial presentation of injury. Other tests such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) scans have proven helpful in identifying traumatic brain injuries. However, these tests are not sensitive to the more subtle effects that accompany a concussion, and are costly to administer (Field et al., 2003). A recently developed method that has proven effective in measuring cognitive decrements associated with concussion is neuropsychological testing (Field et al., 2003).

A concussed athlete exhibits certain cognitive decrements including memory impairment, decreased reaction time, and slower processing speed (Collins et al., 1999). Neuropsychological tests are sensitive to a concussion even when an athlete reports or experiences no post-concussive symptoms. It is important to note that these tests are typically administered to athletes after a concussion and then compared to their pre-injury baseline scores. Recovery is monitored by comparing post-concussion test results taken at different intervals (i.e., usually 24-72 hours post-concussion for the first administration and then every few days or 1-week thereafter) until performance has fully recovered (i.e., near 100% of baseline) and the athlete is asymptomatic.

Neuropsychological testing is valid and reliable in testing the subtle effects of a concussion in the brain (Maroon, Lovell, Norwig, Podell, & Powell et al., 2000). Most experts concur that neuropsychological testing is the new "cornerstone" of concussion management, taking the place of on-field grading systems (Aubry, et al., 2002). Recently, neuropsychological tests have been computerized using multiple, randomized parallel forms, thus, limiting the learning effects inherent in the older paper and pencil versions. One computerized test used for concussion management is the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT: Collins, Field, Lovell, Iverson, & Johnston et al., 2003). Computerized neuropsychological testing provides an individualized, cost-effective and sensitive approach to identifying and treating a concussion (Lovell, Collins, Iverson, Johnston, & Bradley et al., 2004). Computerized neuropsychological testing also provides a measure of both post-concussion symptoms and neurocognitive deficits, and recovery time for concussed athletes. These advances in concussion measurement provide a practical and effective approach for measuring the effects of various factors on concussion outcomes.

1.4. Factors Related to Concussion: Concussion History and Aerobic Fitness

Concussion history. Medical staff, coaches, researchers, and athletes all can agree on one aspect; concussions will continue to occur. The nature of the game of football will always expose athletes to the risk of sustaining a concussion. If researchers could uncover factors that might reduce risk and symptoms and neurocognitive decrements, and improve recovery time, then concussions could be mitigated and possibly prevented. One factor that has been examined in regard to these outcomes is concussion history. When a high school football player sustains a concussion, he is three times as likely to sustain another concussion in the same season (Guskiewicz, Weaver, Padua, & Garrett, 2000). Recent research suggests that the effects of concussion are cumulative (McCrea et al., 2004). Collins and colleagues (2002) reported that athletes with three or more concussions were nine times more likely to incur another concussion and reported significantly more neurocognitive impairments and symptoms than those with fewer than three concussions. Therefore, concussion history is important to consider when examining the risk and effects of concussion.

High school football players may experience more symptoms and neurocognitive impairments, and longer recovery times related to concussion than collegiate and professional athletes. Field, Collins, Lovell, and Maroon (2003) investigated memory decline in high school and college football players suffering from a concussion. They reported that high school athletes experienced more profound cognitive difficulties than college athletes. Moreover, concussed college athletes recovered quicker than high school athletes. Specifically, after being diagnosed with a 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.

Some researchers have suggested that the young, developing brain (i.e., < 19 years) may be more susceptible than the adult brain to concussion and its effects (Grundl, Biagus, Kochanek, Schiding, & Nemoto, 1994; Biagus, Grundl, Kochanek, Schniding, & Nemoto, 1996).

Aerobic fitness. During a concussion, an athlete experiences cognitive deficits including memory impairment, and 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 cognitive function decline has examined the suppressed memory and reaction time of aging individuals. It is generally accepted that a sedentary lifestyle (i.e., low aerobic fitness) contributes to memory "loss" and slower reaction time in older adults. A concussed athlete also experiences brief memory impairment and slower reaction time. Older adults experience a decline in oxygen transport to the brain, neurotransmitter synthesis, and cerebral metabolism (Marchal et al., 1992). 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). Memory scores on neuropsychological tests among memory-impaired older adults have improved from participation in a regular aerobic exercise program (Dustman et al., 1984). Aerobic fitness may result in a more stable increase in oxygen delivery to the brain (Dustman, Emmerson, & Shearer, 1994). Dustman (1984) examined the cognitive improvements experienced by more aerobically fit individuals compared to a non-active control group. The findings of this study support the benefits of aerobic fitness on the cognitive function of the brain. One possible explanation for this improvement is that the brain experiences improved blood flow as a result of aerobic fitness. Support for this contention has been reported in basic laboratory research involving rats. Rats that performed aerobic exercise on a running wheel increased the capillary density in their cerebellum (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990). Aerobic exercise is likely to have a similar effect in humans.

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 may influence brain function. Aerobic fitness may also help to maintain vasodialatory and vasoconstrictive properties in the brain (DeWitt & Prough, 2003). The brain may experience dysautoregulation following concussion, which may slow an athlete's recovery from a concussion. The initial level of aerobic fitness of an injured athlete may mitigate these effects and speed-up recovery time. We speculate that an aerobically fit athlete may also be less likely to be concussed, and experience fewer symptoms and neurocognitive deficits from a concussion.

1.5. Purpose of the Study

Based on the extrapolated evidence from studies of older adults, aerobic fitness (i.e., estimated VO2 max) may influence concussion outcomes. If these findings can be extended to concussion, then more aerobically fit athletes may be at lower risk, and have mitigated symptoms and cognitive impairment from concussion than those who are less aerobically fit. These aerobically fit athletes may also benefit from an expedited recovery from concussion. Therefore, the purpose of the current study was to provide an initial exploration of the relationship of aerobic fitness to concussion risk, symptoms and neurocognitive impairment, and recovery in high school football players. In addition, the researchers hoped to add additional empirical support to the link between concussion history and outcomes in high school athletes; an at risk population for concussion. Hence, the secondary purpose of the study was to examine the relationship of concussion history to concussion risk, symptoms and neurocognitive impairment, and recovery among the same sample. The researchers hypothesized that athletes low in aerobic fitness and those with a history of concussion would be at greater risk for a concussion, and experience more symptoms and neurocognitive impairments, and longer recovery times than athletes high in aerobic fitness and those without a history of concussion. A final purpose of this study was to determine if on-field assessments of PTA in concussed athletes corresponded to ImPACT symptoms and neurocognitive impairment.

2. METHOD

2.1. Research Design

This study employed a prospective, baseline/post-concussion repeated measures design to examine the relationship of aerobic fitness and concussion history to concussion risk, symptoms and neurocognitive impairment, and recovery time.

2.3. Participants

Participants included 158 of an original 190 high school football players from four schools located in the greater New Orleans area. The ages of participants ranged from 14-18 years, with a mean age of 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). To be included in the study each school was required to employ a full-time certified athletic trainer (ATC) on staff during both practices and games. All participants were required to be physically healthy as per their physical examination form and medical clearance by a physician on file prior to the start of the season. Participants indicating on ImPACT any current unresolved concussion, 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. In addition, some participants did not complete all measures. As a result, complete data were available for 158 total participants. The researchers 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 were also collected from participants prior to their participation in the study.

2.4. Measures

2.4.1. Demographics and Exposure.

Participants were asked to complete a questionnaire regarding height, weight, position, age, grade, and playing status (i.e., starter or non-starter). Information regarding exposures (i.e., attendance and participation in contact practices and games) for each athlete was also obtained weekly from coaches.

2.4.2. Aerobic Fitness.

The study employed the three-minute step test protocol from Francis (1990) to measure aerobic fitness. The three-minute step test is one of the most commonly used field tests for predicting oxygen consumption with regards to recovery heart rate. The 3-minute step test has a correlation coefficient of .81 at 26 ascents/min stepping frequency when compared with the Bruce testing protocol (Francis & Brasher, 1992). Instruments used for this protocol consisted of a 16'' step bench, data recording forms, stopwatch, and metronome. The protocol for this test required 10-15 subjects at a time to step up and down from a platform in time with a metronome for a total of 3 minutes. Subjects stepped at a rate of 26 steps per minute for the 3-minute period. This rate was maintained using a metronome, which was pre-set at a tempo of 104 to establish the stepping rate. Participants were divided into groups of 10-15 to complete the test. The researchers instructed subjects on how to assess their heart rate in beats per minute using the palpation method to find their pulse prior to the start of the test. This instruction took place in a lecture setting and participants had the opportunity to ask questions and receive assistance in finding their carotid pulse for a 15 second count. Each subject verbally indicated to the researchers that they were able to find their carotid pulse. Participants were instructed to immediately stop stepping at the termination of the 3-minute period and palpate their carotid pulse. Heart rate was counted for 15 seconds from 5 to 20 seconds post exercise, resulting in a 15 second recovery heart rate value. The researchers then used these values to calculate estimated VO2 max for each participant using the following equation: *VO2 max = 103.42 – (1.588 x 15 second recovery heart rate)*. This study tested multiple participants at a time, something that cannot be logistically completed with larger sample sizes by using other clinical VO2 max assessments (e.g., treadmill tests). The aerobic fitness of the participants was assessed only once during the course of the data collection period. Due to the anaerobic nature of football practices and games, aerobic fitness was assumed to stay consistent throughout the season.

2.4.3. Concussion Reporting.

The medical staffs reported and referred to the researchers any observed, suspected or self-reported concussions in the athletes. Athletic trainers implemented on-field assessments using the University of Pittsburgh Medical Center (UPMC) Sports Concussion program's sideline assessment card. The card assesses orientation to time and place, anterograde and retrograde amnesia, concentration, memory and various concussion signs and symptoms. Presence of these on-field markers warranted referral to the researchers for post-injury neuropsychological testing using ImPACT. Emergent severe closed and open head injuries (as determined by the medical staff) were excluded from the study and were treated by each school's medical staff in accordance with each school's policies.

2.4.4. Computerized Neuropsychological Testing.

The ImPACT Version 2.0 test and symptom inventory neuropsychological testing software is a reliable measure that allows for individual concussion assessment and management (Collins, Stump, & Lovell, 2004). This test is a time efficient, sensitive, valid, and cost-effective way to evaluate concussion. In a study on ImPACT by Iverson, Lovell, and Collins (2003), no practice effects were seen in two-week test-retest interval. The researchers also reported reliable correlation coefficients for the composite scores of each test battery ranging from .65 to .86. The ImPACT test consists of a battery of computerized tests that comprise six different modules. The modules include 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 results are examined using four composite scores: (a) verbal memory (% correct), (b) visual memory (% correct), (c) processing speed (#: higher #= better performance), and (d) reaction time (sec- lower # = better performance). The test was administered to 20-30 participants at a time using networked computers at each school. This 30 minute self-paced test also includes questions about symptoms, concussion history, and other related factors (e.g., learning disability, mental health history). The test was administered at baseline (i.e., preseason) to all participants, and then again to any participant who incurred a suspected concussion. Post concussion administration was conducted at 24-72 hours post injury and again every 48-72 hours thereafter until the athlete returned to baseline. Concussion symptoms and neurocognitive impairment, and recovery were monitored by each school's medical staff in conjunction with the UPMC Sports Concussion program.

2.5. Procedures.

Permission from pertinent school administrators, coaches and medical staff was obtained prior to data collection. Parental consent and participant assent were also obtained from participants at a brief informational meeting with each team. After each school consented to participate in the study, a site analysis was conducted by the researchers 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 3-minute step assessment were conducted with five volunteers who were then excluded from the study. All ATCs were instructed in the use of the concussion card to identify concussion symptoms presented by their respective athletes. Athletic trainers were given the sideline assessment card, and were reminded to indicate which concussed athletes, if any, experienced PTA. At this time, they also had the opportunity to ask the researchers any questions on what constituted referral for post-concussion testing. Coaches were instructed on how to tabulate practice and game exposures for their players. Prior to baseline testing, participants completed a written demographic form including information on age, height, weight, position, grade, and playing status. Aerobic fitness was then assessed using the 3-minute estimated VO2 submaximal step test described earlier. The data were then recorded and inserted into the equation described earlier to estimate VO2 max.

Approximately 24 hours after the aerobic fitness testing, neuropsychological testing was conducted. Baseline ImPACT testing was administered in the computer labs at each respective school. All ImPACT tests were administered to groups of approximately 20-30 participants depending on the available number of computers. During the course of the competitive football season, player attendance and the total number of practices and games players participated in was obtained from coaches by the researchers via weekly telephone calls and interviews. During the season, all players who incurred a suspected concussion based on physical markers present in the athletes were referred by ATCs or physicians to the researcher for post-injury ImPACT testing. To insure that all concussions were reported, the researcher called each ATC twice per week to remind them and determine if any potential concussions have occurred that were not immediately reported. The medical staffs appeared to be compliant with the concussion assessments and referral protocol. Any players who incurred severe closed (e.g., subdural hematoma) or open (e.g., skull fracture) head injuries were not tested, as they required emergent medical care from the team medical staff or other medical providers. Each concussed player was administered the ImPACT retest at his school within 24-72 hours of a concussion. Follow-up ImPACT tests were administered again every 48-72 hours until the concussed athlete was asymptomatic and returned to baseline neurocognitive performance.

2.6. Data Analysis.

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) 11.5 software. Participant demographic information was summarized using descriptive data (see Section 2.2.). Aerobic fitness was examined using normative (ACSM, 2000) and descriptive data. Concussion incidence rates were calculated. A series of MANOVAs were used to examine differences in baseline ImPACT module scores and symptoms between the following groups: (a) concussed and non-concussed, (b) high and low estimated VO2 max, and (c) concussion history and no concussion history. To examine the relationship of on-field PTA to ImPACT symptoms and neurocognitive impairment, chi-square and odds ratio (OR) analyses were used to compare the number of reliable cognitive declines (using an 80% CI reliable change estimate [RCE]) presented at 24-72 hours post-concussion in athletes. We used the same RCE formula and 80% CI as suggested by Iverson, Lovell and Collins (2003). Chi-square and OR analyses were also used to compare the likelihood that concussed athletes experienced one or more cognitive declines, and two or more cognitive declines on ImPACT. Chi-square and OR analyses were also used to compare concussion risk among aerobic fitness (high vs. low) and concussion history (concussion history vs. no concussion history) groups. A series of 2 (concussion history) x 2 (aerobic fitness) repeated measures

ANOVAs were used to compare the baseline and post-concussion symptoms and neurocognitive impairment of concussed athletes. Chi-square and OR analyses were used to compare the likelihood that aerobic fitness groups and concussion history groups experienced one or more cognitive declines, and two or more cognitive declines on ImPACT. A 2 (aerobic fitness) x 2 (history of concussion) x 2 (on-field PTA) ANOVA was used to examine concussion recovery time. Statistical significance for all analyses was set at a p>.05.

3. RESULTS

3.1. Aerobic Fitness.

Demographic data were collected using the preseason questionnaire and ImPACT test. Prior to the start of the season aerobic fitness was assessed using the 3-minute step test. The mean estimated VO2 max value for this sample was low at 36.29 ml/kg/min (SD= 11.32). Only 27% (n= 42) of 37 participants were classified as high estimated VO2 max based on the criteria (estimated VO2 max= 44.20 ml/kg/min) provided by the ACSM (2000). Consequently, a median (estimated VO2 max= 36.72 ml/kg/min) split method was used to create high and low estimated VO2 max classifications. Using this method, there were 83 participants who had a low (<36.72 ml/kg/min) estimated VO2 max and 75 (>36.72 ml/kg/min) who had a high estimated VO2 max.

3.2. Concussion Rates.

Twenty-three players reported having at least one concussion in this study, which represents approximately 13% of the total sample. Thirty-five percent (n= 8) 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 was not recorded as an additional case. Of the 23 reported concussions, 7 included PTA as a symptom during on-field assessments at the time of injury. A total of 21% of the participants reported at least one previous concussion (n= 33). The mean number of previous concussions for the total sample was 0.32 (SD=0.92). There were 7,612 total exposures (practice and game) during this study. The concussion incidence rates for this study were 2.63 concussions per 1000 exposures, and 12.66 concussions per 100 participants.

3.3 Baseline ImPACT Data.

In general, the baseline ImPACT module scores for this sample were below the published ImPACT normative data (Iverson, Lovell & Collins, 2003) for the same age group (see Figure 1). We collapsed the published norms for 13-15 years and 16-18 years age groups into one average group to correspond to the current sample's age range (14-18 years). According to these normative data classifications, the participants in this study were classified as slightly below average on most modules.

Table 1. A Comparison of Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) Baselines Scores in the Current Sample (N= 158) to Normative Data.

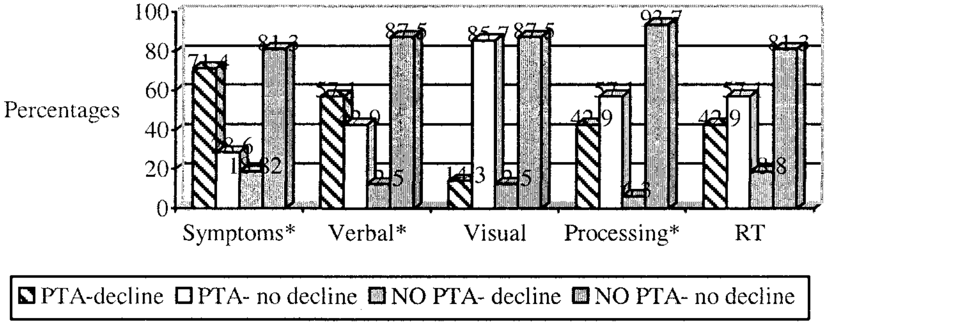
ImPACT Module	Current sample *Mean*	Current sample *SD*	Normative data 50^{th} percentile
Symptoms	10.49	0.10	NA
Verbal memory	0.79	0.14	0.87
Visual memory	0.69	7.98	0.78
Processing speed	31.90	0.11	35.87
Reaction time	0.57	10.87	0.55

The results of a MANOVA (Wilk's λ = .96, F [5, 179] = 1.53, η^2= .04, p = .18) comparing concussed and non-concussed participants in the current sample indicated no significant differences in baseline ImPACT module and symptom scores. Similarly, the results of a MANOVA (Wilk's λ = .98, F [5, 179] = .75, η^2= .02, p= .59) for high and low estimated VO2 max groups revealed no significant differences in baseline ImPACT module and symptom scores. The results of the MANOVA (Wilk's λ = .99, F [5, 179] = .44, η^2= .01, p= .82) for concussion history groups was also not significant. These data suggest that the participants in these groups were similar in regard to baseline ImPACT module scores and symptoms, negating potential confounds at baseline. Hence, any differences between baseline and post concussion scores and symptoms were likely a result of concussion.

3.4. On-field Post-traumatic Amnesia and Concussion Symptoms and Neurocognitive Impairment as Measured by ImPACT.

As expected, the results of a series of chi-square analyses indicated that concussed athletes who reported PTA were more likely to experience cognitive declines (using RCEs at an 80% CI) on ImPACT than concussed athletes without PTA (see Figure 1). Specifically, concussed athletes with

PTA experienced significantly more symptoms (χ^2= 5.96, *p*= .02, *OR*= 10.83, *95% CI*= 1.37-85.44), verbal memory (χ^2= 5.03, *p*= .03, *OR*= 9.33, *95% CI*= 1.16-15.46) and processing speed (χ^2= 4.54, *p*= .03, *OR*= 11.25,



***p*<.0.05**

Fig. 1. A comparison of the percentage of athletes with PTA (n=7) and without PTA (n=16) who experienced post-concussion cognitive declines as measured by Immediate Postconcussion Assessment and Cognitive Testing (ImPACT).

95% CI= .91-139.49) declines than those without PTA. There were no differences in visual memory and reaction time declines. The results of two additional chi-square analyses (χ^2= 7.74, *p*= .005; χ^2= 3.39, *p*= .05) indicated that concussed athletes with PTA were 11.7 (*95% CI*= 1.14-119.55) times more likely to experience at least one cognitive decline and 5.8 (*95% CI*= 0.82-40.80) times more likely to experience at least two cognitive declines on ImPACT than concussed athletes without PTA. In summary, on-field assessments of PTA among concussed athletes corresponded to higher symptoms and neurocognitive impairment on ImPACT.

3.5. Concussion Risk.

The results of a chi-square analysis (χ^2= 1.42, *p*= .23) supported a non-significant trend suggesting that athletes low in estimated VO2 max (*n*=83) were 1.80 (*95% CI*= 0.68-4.80) times more likely to incur a concussion than those high in estimated VO2 max (*n*= 75). The results of a chi-square analysis (χ^2= 7.16, *p*= .007) indicated that athletes with a history of concussion (*n*= 29) were 3.71 times (*95% CI*= 1.36-10.18) more likely to be concussed in the current study than those who had no history of concussion (*n*= 129).

3.6. Post-concussion Symptoms and Neurocognitive Performance.

The results of a series of 2 (aerobic fitness) x 2 (concussion history) repeated measures ANOVAs assessing within and between subjects differences on ImPACT module and symptom scores from baseline to 24-72 hours post-concussion revealed a within subjects main effect ($F[1, 23]= 10.08$, $p= .008$, $\eta 2= .46$) for concussion history on processing speed (see Table 2). Unexpectedly, athletes with a history of concussion reported an increase in processing speed from baseline to post-concussion, whereas

Table 2. Baseline and 24-72 Hours Post-concussion Descriptive Statistics for Concussion History on Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) Module and Symptom Scores.

	Concussion History							
	Baseline				24-72 Hours Post-Concussion			
ImPACT Module	History		No History		History		No History	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Total Symptoms	14.0	13.6	10.6	10.5	19.2	11.1	12.7	13.7
Verbal Memory	0.68	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	0.14
Processing Speed	32.0*	7.56	31.87*	8.10	38.5*	4.51	32.6*	9.6
Reaction Time	0.62	0.10	0.57	0.11	0.63	0.21	0.54	0.08

$^*p< .0.05$

athletes with no history of concussion reported a decrease. No within or between subjects main effects or interactions for aerobic fitness were supported (see Table 3 for descriptive results). The remainder of the between and within subjects main effects and interactions for concussion history were not significant. Descriptive statistics indicated that athletes high in aerobic fitness scored slightly (though not significantly) worse on some modules of ImPACT after concussion than those low in aerobic fitness. We speculated that the relationship between aerobic fitness and ImPACT module and symptom scores may be affected by on-field presence of PTA. However, given the small sample of concussed athletes in this study, we lacked the power to include PTA as an additional independent factor in our analyses.

Table 3. Baseline and 24-72 Hours Post-concussion Descriptive Statistics for Aerobic Fitness on Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) Module and Symptom Scores.

	Aerobic Fitness (i.e., estimated VO2 max)							
	Baseline				24-72 Hours Post-Concussion			
ImPACT Module	High		Low		High		Low	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Total Symptoms	7.66	8.14	12.27	10.2	13.7	14.9	17.4	13.6
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
Processing Speed	35.3	10.4	33.2	6.3	35.6	11.9	33.2	6.7
Reaction Time	0.52	0.05	0.56	0.10	0.55	0.06	0.58	0.19

The results of a series of chi-square analyses indicated no significant differences in the number of post-concussion cognitive declines (using RCEs at an 80% CI) between athletes high in aerobic fitness and those low in aerobic fitness (see Figure 2). Similarly, the results of a series of chi-square analyses indicated no significant differences in the number of post-concussion cognitive declines (using RCEs at an 80% CI) in processing speed between athletes with a history of concussion and those with no history of concussion (see Figure 3). However, we found it peculiar that athletes with a history of concussion reported nearly three times as many symptom declines (i.e., reliable increases in the number of symptoms) as those with no history of concussion, but did not experience any visual memory or processing speed declines.

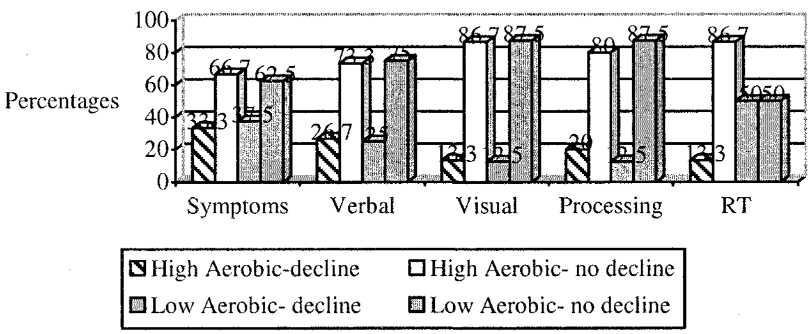


Fig. 2. A comparison of the percentage of athletes high (n= 8) and low (n= 15) in aerobic fitness who experienced post-concussion cognitive declines as measured by Immediate Postconcussion Assessment and Cognitive Testing (ImPACT).

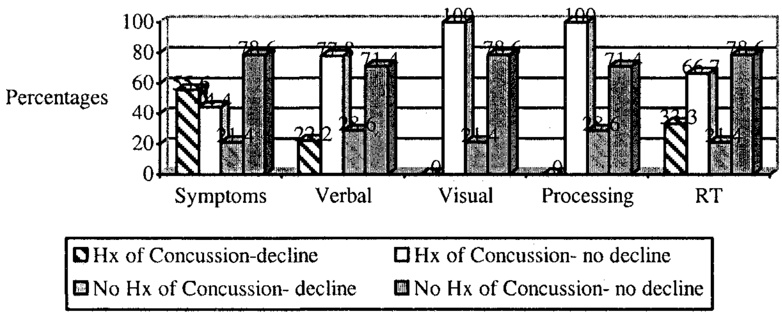
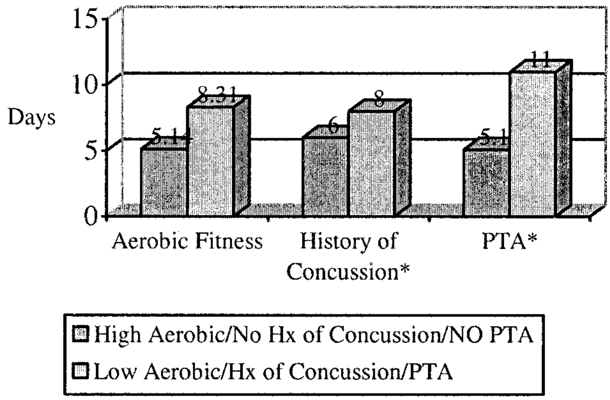


*Fig. 3. A comparison of the percentage of athletes with a history of concussion (*n= *9) and with no history of concussion (*n= *14) who experienced post-concussion cognitive declines as measured by Immediate Postconcussion Assessment and Cognitive Testing (ImPACT).*

The results of two chi-square analyses (χ^2= 0.21, *p*= .65; χ^2= 0.29, *p*= .59) suggested that aerobic fitness was not predictive of one or more, or two or more cognitive declines after a concussion. Similarly, the results of two other chi-square analyses (χ^2= 0.01, *p*= .94; χ^2= 0.06, *p*= .81) suggested that history of concussion was not predictive of one or more, or two or more cognitive declines after a concussion. In summary, neither aerobic fitness nor concussion history played a significant role in concussion symptoms and neurocognitive impairment.

3.7 Concussion Recovery

The results of a 2 (aerobic fitness) x 2 (concussion history) x 2 (on-field PTA) ANOVA supported significant main effects for concussion history (F[1, 23]= 4.00, p=.05, $\eta 2$= .25) and on-field PTA (F[1, 23]= 12.10, p=.005, $\eta 2$= .50) on recovery time. Specifically, athletes with no history of concussion recovered faster than those with a history of concussion (see Figure 4). Concussed athletes who were evaluated with no on-field PTA recovered faster than those who were evaluated with PTA. There was also a non-significant trend for aerobic fitness (F[1, 23]= 2.10, p= .07, $\eta 2$= .15), suggesting that athletes high in aerobic fitness recovered faster than those low in aerobic fitness. The results did not support any interactions among the factors.



*p<.05

Fig. 4. A comparison of the concussion recovery times for athletes high (n= *8) and low* (n= *15) in aerobic fitness, with a history of concussion* (n= *9) and with no history of concussion* (n= *14), and with no PTA* (n= *16) and with PTA* (n= *7).*

4. DISCUSSION

This study provided an initial examination of the relationship of aerobic fitness and other factors to concussion outcomes. The results of the current study suggest that aerobic fitness and concussion history might play a role in concussion risk and recovery, but not in symptoms and neurocognitive declines. A summary of the results and a discussion of the findings and limitations of the study are presented below. Implications of the current study's findings for sport medicine professionals, coaches, parents, and athletes are presented throughout the discussion.

4.1. Summary of Results.

The results of the current study indicated that the aerobic fitness of this sample of high school football players was considerably below the relative VO2 max norms of the ACSM (2000). The concussion incidence rate in this study was 12.66/100 participants, which appears to be high; however, the 2.63/1000 exposures incidence rate suggests that the concussion rate in the current study is in line with previous research in high school football. The ImPACT test corresponded to initial on-field evaluations of PTA. Concussed athletes with PTA were nearly 12 times more likely to have one or more cognitive declines, and nearly 6 times more likely to have two or more cognitive declines on ImPACT than concussed athletes with no PTA. Athletes with a history of concussion were nearly four times more likely to have a concussion in the current study than those with no history of concussion. A non-significant trend suggested that athletes high in aerobic fitness in the current study were nearly two times more likely to have a concussion than those low in aerobic fitness. No relationships between aerobic fitness or concussion history and symptoms and neurocognitive impairment were uncovered. Athletes with a history of concussion and those with on-field PTA recovered more slowly than those with no history of concussion and no on-field PTA. A non-significant trend suggested that athletes high in aerobic fitness recovered faster than those low fitness.

4.2. Concussion Rates.

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. The first rate is in line with previous research (Powell & Barber-Foss, 1999). However, the second rate is much higher than the concussion incidence rate of 3.66 per 100 high school football players reported by Powell and Barber-Foss (1999). As eluded to earlier in Section 1.2, discrepancies in reported concussion incidence rates such as these can usually be attributed to differences in the recording of exposures. For example, 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 exposure incidence rate may reflect a slightly lower incidence of concussion due to an inflated number of exposures per player. None the less, the 12.66 per 100 participants concussion incidence rate in this study may reflect an actual increase in concussion incidence or a peculiarity (e.g., quality of competition, instruction, and equipment) associated with the current sample.

4.3. On-field Post-traumatic Amnesia and Concussion Symptoms and Neurocognitive Impairment as Measured by ImPACT.

The results indicated that the ImPACT test corroborated initial on-field evaluations of PTA in the current study. Concussed athletes with PTAwere nearly 12 times more likely to have one or more cognitive declines, and nearly 6 times more likely to have two or more cognitive declines on ImPACT than concussed athletes with no PTA. These results are line with previous research, which suggested that concussed athletes were 46 times more likely to have two or more cognitive declines on ImPACT than non-concussed controls (Iverson, Lovell & Collins, 2003). The lower ORs in the current study can be attributed to the within concussion comparison groups of PTA versus no PTA. The findings in the current study lend support to the growing body of evidence (e.g., Collins et al., 2004; Lovell & Collins, 2003) indicating that ImPACT is a valid measure for assessing concussion outcomes. The findings also support the notion that PTA may be a valid indicator of post-concussion neurocognitive impairment and symptoms (Collins, Iverson, Lovell, McKeag, and Norwig, et al., 2003). The findings can be viewed in reverse, suggesting that on-field evaluations employing empirically-based signs and symptoms such as PTA are valid in predicting neurocognitive symptoms and impairment.

4.4. Concussion Risk.

A non-significant trend indicated that individuals low in aerobic fitness were nearly two times more likely to be concussed during this study than high aerobically fit athletes. This finding partially supports our suggestion that aerobic fitness may insulate athletes from the effects of potentially concussive impacts, much like it does for cognitive decline in older adults (Dustman et al., 1984). An alternate explanation is that aerobic fitness decreases fatigue in athletes. It is generally accepted that as athletes become fatigued, they are more likely to be distracted, less likely to react appropriately to the environment, and potentially more likely to be injured. The same may be true for concussion. Hence, aerobic fitness may help to reduce fatigue and thereby, indirectly affect concussion risk. However, given the lack of significance for this finding, the current study needs to be extended and replicated with significant results before any explanations or mechanisms should be explored.

Athletes with a history of concussion were nearly four times more likely to have a concussion in the current study than those with no history of concussion. This finding lends support to the contention that effects of concussion may be cumulative, and that increased risk is associated with a history of concussion (Iverson et al., 2004). The current study delineated two concussion history groups: (a) one or more previous concussions, and (b) no previous concussions.

4.5. Post-concussion Symptoms and Neurocognitive Performance.

The current study provided little evidence of any relationships between either aerobic fitness or concussion history, and concussion symptoms and neurocognitive performance. Based on the current findings, concussion symptoms and neurocognitive impairment appear to occur irrespective of aerobic fitness and concussion history. Although, one could argue to the contrary that the lack of cognitive declines in visual memory and processing speed associated with concussion history in the current study suggests that athletes with a history of concussion may be more attune to their injury, and be able to compensate with the familiar decrements in performance associated with it. The lack of support for a relationship between concussion history and symptoms and neurocognitive impairment is in contrast to previous findings (e.g., Collins et al., 2002; Iverson et al., 2004).

4.6. Concussion Recovery Time.

4.6.1. Aerobic Fitness.

A non-significant trend in the current study suggested a possible 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 an average recovery time of eight to nine days post concussion. However, the concussed high aerobic fitness group had a recovery time of approximately five days post concussion. This three to four day improvement in recovery time suggests that the benefits (i.e., blood vessel elasticity, increased stroke volume) of being more aerobically fit as described in Dustman et al. (1984), might enhance recovery of the brain after a concussion. However, a post-hoc non statistical review of the descriptive data suggested that the presence of on-field PTA may also play a role in this potential trend. We found that the concussed athletes with PTA had longer recovery times than concussed athletes without PTA regardless of aerobic fitness levels. Post-traumatic amnesia is may be related to damage to deeper structures of the brain. This may indicate that aerobic fitness is a protective factor only in concussions without PTA, or those wherein the biomechanical impact was less. Larger samples of concussed athletes with and without PTA are needed to explore this possible interaction.

Overall, this initial evidence partially supports the hypothesized relationship between aerobic fitness and concussion recovery. Occasionally, researchers become too focused on statistical significance and ignore what Iverson, Lovell and Collins (2003) referred to as, 'clinically meaningful', though potentially non-significant findings. We would suspect that most medical staff, coaches, players and parents would be thrilled with the potential 2-3 day reduction in recovery time from a concussion associated with aerobic fitness, as it represents a clinically meaningful improvement.

Regardless, this trend warrants further investigation and identifies aerobic fitness in high school athletes as a possible mitigating factor in recovery from concussion.

4.6.2. Concussion History and On-field PTA.

The results of the current study indicated that a history of concussion was associated with slower recovery time. This finding lends additional empirical support to the proposed cumulative effects of concussion (Collins et al., 2002). One implication of this result is that athletes should be given a 'brain physical' at the beginning of any athletic season. At the very least, medical staff should know the concussion histories of their athletes to allow for better management of concussion and safer return to play decisions.

As expected, initial on-field evaluations of PTA corresponded to longer recovery times. This finding highlights the importance to medical staffs of providing an initial assessment of concussed athletes using such empirically-based signs and symptoms as PTA, as included in the UPMC concussion card used in the current study. In doing so, concussed athletes will be managed in a more appropriate manner. In the future, such brief initial evaluations of PTA may become as effective as current brief ankle and knee evaluations in predicting recovery time; though more empirical data are needed before this can become a reality.

4.7. Limitations and Suggestions.

There were several limitations of this study and methods used to collect the data. The study was limited by the small sample of concussed athletes. This limitation reduced the statistical power of the current analyses and precluded more sophisticated analyses from being run. A larger sample size may help to reinforce or refute the non-significant trends that were found regarding the aerobic fitness and concussion risk and recovery in high school athletes. To this end, the current researchers have expanded this study to include a considerably larger sample of athletes.

Another limitation of this study was the low overall aerobic fitness of the participants. This may have affected the potential to assess real differences in aerobic fitness, as the sample was tightly clustered on the low end of the continuum. A more purposeful sampling method might eliminate this problem. However, as one coach in our study put it, "These are high school football players, not marathon runners!"

A final limit of this study was that it did not directly measure possible changes in the brain associated with aerobic fitness before or after concussion. Such measures would substantiate the indirect relationships postulated in the current study. The use of MRI and f-MRI technology would be ideally suited to directly link aerobic fitness to changes in the brain, and to subsequent concussion outcomes.

CONCLUSION

In summary, aerobic fitness may be related to concussion risk and recovery. More research with a larger sample of concussed athletes needs to be done to substantiate these tentative findings. Ultimately, researchers will need to directly link aerobic fitness with actual changes in brain function and concussion outcomes. There was no evidence to suggest that aerobic fitness was related to concussion symptoms and neurocognitive impairment. Relationships between concussion history and increased concussion risk and slowed recovery were evident in this study, lending support to previous research (Collins et al., 2002). The lack of cognitive declines in visual memory and processing speed following a concussion among athletes with a history of concussion was anomalous and warrants further investigation. Initial on-field evaluations of PTA corresponded to subsequent post-concussion symptoms and cognitive declines on ImPACT, reinforcing the validity of ImPACT as a measure of concussion outcomes. On-field evaluations of PTA also corresponded to recovery times, indicating that medical staffs should employ assessments of on-field PTA to better manage concussion; as suggested by Collins, Iverson, Lovell, McKeag, and Norwig, et al. (2003).

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