

EXAMINATION OF TEST-RETEST RELIABILITY OF A COMPUTERIZED
NEUROCOGNITIVE TEST BATTERY

By

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ABSTRACT

EXAMINATION OF TEST-RETEST RELIABILITY OF A COMPUTERIZED NEUROCOGNITIVE TEST BATTERY

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Context: Test-retest reliability is a critical issue in utilization of computerized neurocognitive assessments employing pre-participation baseline test followed by a series of post-concussion tests. Low test-retest reliability was reported by Broglio et al. (2007) for one of the most widely used neurocognitive test battery, Immediate Post Concussion Assessment and Cognitive Testing (ImPACT) with specific testing intervals.

Purpose: The purpose of this study was to re-examine the test-retest reliability of ImPACT between baseline, 45 days and 50 days after baseline.

Methods: A total of 88 physically active college students (54 male, 34 female) volunteered for this study. A repeated-measures design was used with test group (administration of ImPACT at baseline, 45days after the baseline, and 50 days after the baseline) as the independent variable and ImPACT composite scores (Verbal Memory, Motor Processing Speed, and Reaction Time) as the dependent variables. The pre-testing survey was administered to assess the participants' physical activity level and physical and mental condition on the testing day. Following the pre-testing survey, the Rey's 15-item memory test was administered before each ImPACT administration as an effort measurement. Following ImPACT, the post-testing survey was administered to assess the testing environment.

Results: Intraclass correlation coefficients between baseline to Day 45, Day 45 to Day 50, baseline to Day 50, and overall intraclass correlation coefficient were reported as follows: visual memory (.76, .69, .66, .78), verbal memory (.72, .66, .60, and .75), motor processing speed

(.86, .87, .84, .90), and reaction time (.68, .83, .72, and .81). All intraclass correlation coefficient values exceeded the threshold value of .60 for acceptable test-retest reliability. The pre and post-testing survey with 0 to 10 likert scales revealed the participants were moderately stressed (average 4.64) and mildly fatigued (average 3.45), with low level of distraction (average 1.73) while completing the ImPACT test. With an exception of one participant, all participants scored perfect on Rey's 15-item Memory test.

Conclusion: Results of this study suggest that ImPACT is a reliable neurocognitive test battery over 45 and 50 days after baseline assessment. The current study's findings agree with other test-retest reliability studies that have reported acceptable intraclass correlation coefficients over different testing intervals, which support the utilization of ImPACT for the multidisciplinary approach to concussion management.

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CHAPTER I

INTRODUCTION

Sporting activities are second to motor vehicle crashes as the leading cause of traumatic brain injury (TBI). In the 1990's there were approximately 300,000 sports-related concussions reported annually in the United States. Recently it has been estimated that 1.6 to 3.8 million mild TBIs occur in sports and recreational activities among individuals aged 15 to 24 years in the United States annually (Langlois, Rutland-Brown, & Wald, 2006). Increases in the number of athletes participating in sports, increased public awareness about concussion through media and programs such as the *Heads UP* program by Centers for Disease control and Prevention (CDC), and the improvement in concussion diagnosis are thought to be the reasons for this significant increase in concussions.

Even though the origin of the term is clear (*concutere*, means dash together, to shake violently or *concussus*, means action of striking together), defining a concussion has been a difficult task due to its complex nature of symptoms and cognitive impairments associated with concussion. To date, researchers and clinicians have not come to a consensus on the exact definition of sport-related concussion. In the latest International Conference on Concussion in Sport (CIS) a concussion was defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces (McCrory et al., 2009). The CIS group also suggested five common features of sport-related concussion including: 1) concussion can be caused by direct impact to the head, face, neck, or elsewhere on the body with an “impulsive” force transmitted toward the head; 2) concussion typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously; 3) concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional

disturbance rather than structural injury; 4) concussion results in a graded set of clinical syndromes that may or may not involve LOC; and 5) concussion is typically associated with grossly normal structural neuroimaging studies (McCrory et al., 2009).

Epidemiological studies have been conducted based on the data from Reporting Information Online (RIO) for high school population and National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) for collegiate population. The latest epidemiological study utilizing the RIO reported that approximately 2.5 concussions per 10,000 athlete exposures (A-Es) occurred in this population (Marar, McIlvain, Fields, & Comstock, 2012). For collegiate population, a study utilizing the NCAA ISS summarized 16 years (1988 to 2004) of injury data from 15 NCAA sports and reported approximately 3.4 concussions per 10,000 A-Es (Hootman, Dick, & Agel, 2007). Even though cautions are needed for interpretation of the data (e.g., number and type of sports studied), these data suggest that collegiate athletes may have slightly higher injury rates than high school athletes.

The signs and symptoms of concussion typically fall into 4 categories: physical, cognitive, emotional, and sleep disturbances (Almasi & Wilson, 2012). Typical signs and symptoms of a concussions include headache, nausea, dizziness, fatigue, vomiting, balance problems, and sensitivity to light and noise as common physical symptoms (Barth et al., 1989; Cantu, 1998a; Maddocks & Dicker, 1989). Mental foginess, difficulty in concentrating, decreased processing speed, and memory difficulties are common cognitive symptoms (Maruta, Lee, Jacobs, & Ghajar, 2010). Emotional symptoms including personality change, sadness, nervousness, and sleep disturbance may be observed in some concussed athletes (Guskiewicz et al., 2006; Lovell et al., 2006; McCrory et al., 2005).

Detecting probable concussion is important to prevent more serious consequences, such as second-impact syndrome (SIS) that often results in brainstem herniation and death (Cantu, 1998). Even though self-report from athletes becomes such an important part for detecting probable concussion, the underreported nature of concussion has long been a problem in sport participation. There are several reasons why athletes do not report their concussion such as underestimation of seriousness of injury, motivation to stay in competition, cluelessness of the signs and symptoms of concussion (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). Due to this underreported nature of concussion, estimation of concussion incident is thought to be a conservative estimate. Evaluation and management for concussed athletes have been improved with utilization of computerized neurocognitive assessments and individualized management protocols.

Traditionally, major on-field markers for concussion have been thought to be loss of consciousness (LOC) and post traumatic amnesia (PTA) (McCrea, Kelly, Randolph, Cisler, & Berger, 2002). In fact, the status of LOC and PTA have been used in most of the grading scales to determine grade and severity of concussion. However, the most recent consensus statement from the International Conference on CIS stated that the status of clinical post-concussive symptoms is more important than the presence or duration of PTA and LOC (McCrory et al., 2009). These findings have contributed to the improvement of management guidelines that used to put emphasis on the status of PTA and LOC.

Management guidelines published over the past two decades are largely based on the opinions of groups of experts rather than on empirical research (Collins, 1999); therefore, consensus statements have suggested the abolishment of historically utilized concussion grading scales (Aubry et al., 2002; Mccrory et al., 2005; 2009). In consequence, the management and

return to play strategies for sports-related concussion have been refined through re-evaluation and revision of prior guidelines. Currently, a medically supervised step-wise return-to-play process is similarly recommended by the CIS and National Athletic Trainers' Association (NATA) position statements (Aubry et al., 2002; McCrory et al., 2005; 2009). Based on the possibility of symptoms returning from progressive physical and sport-specific exertion, a total of six stages were recommended from complete rest with no activity until asymptomatic (stage 1) to full contact training after medical clearance (stage 5) and return to play (stage 6) (McCrory et al. 2009; Guskiewicz et al., 2004). Injured athletes proceed to the next level if they remain asymptomatic at the current stage or they must go back to the previous asymptomatic stage if their concussion symptoms return. The progression resumes after 24 hours of physical and cognitive rest (McCrory et al., 2009). Along with the development of step-wise progression for return to play protocols, the utilization of computerized neurocognitive test batteries is another area of improvement in concussion management.

Neuropsychological assessments have evolved from traditional paper and pencil measurements (e.g., Paced Auditory Serial Addition Test, the Trail-Making Test A and B, and the Digit Symbol Test etc.) to computerized neuropsychological assessments in order to overcome the weaknesses of traditional methods such as high cost, difficulty of administration and evaluation, learning effects, and sensitivity (Collins & Hawn, 2002; Hinton-Bayre, Geffen, Geffen, McFarland, & Friis, 1999; McCrea et al., 2005). There are several computerized neurocognitive assessment programs available including the Automated Neuropsychological Assessment Metrics sports medicine battery (ASMB), CogSport, the Concussion Resolution Index (CRI), and the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT). These computerized neuropsychological test batteries measure several domains of cognitive

function including working memory, attention, concentration, short-term verbal and non-verbal memory, and reaction time.

Currently, utilization of computerized neurocognitive assessments employing pre-participation baseline test followed by a series of post-concussion tests have become a crucial element of the multidisciplinary approach to concussion evaluation and management (Guskiewicz et al., 2004; McCrory et al., 2009). The advantage of employing baseline testing is to minimize possible confounding factors such as age, sex, and individual's cognitive strength and weaknesses (Bernhardt, 2000; Guskiewicz et al., 2004). Obtaining baseline testing data enables more individualized concussion management.

The ImPACT test battery is a widely used neuropsychological assessment program that evaluates multiple aspects of neurocognitive function including concentration, attention, memory, visual motor speed, and reaction time. The ImPACT test battery consists of three main parts: demographic data, Post-Concussion-Symptom Scale (PCSS), and the neuropsychological tests modules. Some variables obtained in the demographic data consist of subjects' sport, medical, and concussion history. The PCSS is comprised of 22 symptoms rated on a seven-point Likert scale (0 to 6), and is used to document and track concussion symptoms. The neuropsychological modules are comprised of six tests that measures memory, attention, concentration, visual-spatial, and working memory. ImPACT generates four composite scores: verbal memory, visual memory, visuomotor speed, and reaction time. Impulse control composite score is also generated in order to detect an invalid test due to test takers' lack of effort or too many errors. Currently, the ImPACT test can be administered online, which enhances the ease of use of this assessment tool. Several studies have been conducted regarding sensitivity, specificity, reliability, and validity of ImPACT test battery.

High sensitivity (81.9%) and specificity (89.4%) (Schatz, Pardini, Lovell, Collins, & Podell, 2006) and good construct validity with standardized neuropsychological tests ($r=.34-.59$, $p<.001$) (Maerlender et al., 2010) of ImPACT have been reported. As for the reliability, with a 7-day time span, Iverson et al.(2003) reported moderate to high Pearson test-retest correlation coefficients for the following composite scores: verbal memory $=.70$, visual memory $=.67$, reaction time $=.79$, processing speed $=.89$ and post-concussion scale $=.65$. With a 4-month time span, Miller et al. (2007) reported no significant difference in all composite scores when 80% confidence interval was used ($p=.04$ for visual memory and reaction time, $p=.05$ for processing speed, $p=.06$ in verbal memory). With a 1-year time span, Elbin et al. (2011) reported ICC values of .85 for motor processing speed, followed by reaction time (.76), visual memory (.70), verbal memory (.62), and post-concussion symptom scale (.57). Finally, with a 2-year time span, Schatz et al. (2010) reported ICC of .74 for motor processing speed, followed by reaction time (.68), visual memory (.65), verbal memory (.46), and then total symptom score (.43). Even though ICC and correlation coefficients varies over studies and composite scores, the recommended acceptable ICC threshold (.6) by Baumgartner et al. (2001) is satisfied in most of the cases.

However, Broglio and colleagues (2007) reported low ICC for all ImPACT composite scores through three test administrations: baseline, 45 days after the baseline, and 50 days after the baseline. The ICC for each composite score were as follows: verbal memory (.23 for baseline to day 45, and .40 for day 45 to day50), visual memory (.32 and .39, respectfully), motor processing speed (.38 and .61, respectfully), and reaction time (.39 and .51, respectfully). These low ICC values may have been attributable to methodological problems caused by administering three different computerized neurocognitive assessments in succession (ImPACT, Headminder's

CRI, Concussion Sentinel). Also, the uncontrolled physical activity level of the participants might have affected the result of this study as studies have reported the positive effect of physical activity on cognitive function of young adults (Hillman, Kramer, Belopolsky, & Smith, 2006; Kamiyo & Takeda, 2009). While other studies that showed acceptable ICC and correlation coefficients used athletes as their study participants, Broglio and colleagues (2007) used “healthy college students” with no description of their physical activity level. To date, no study has been conducted to re-examine the test-retest reliability of ImPACT for mid-term (45-50 days) after Broglio et al.(2007) reported low ICC even though their methodological problem has been pointed out numerous times. In addition, no study has controlled for physical activity level and other possible confounding variables such as hours of sleep and caffeine intake.

Purpose of the Study

The purpose of this study is to re-examine the test-retest reliability of the ImPACT neurocognitive test battery between baseline, 45 days and 50 days after baseline on physically active college students.

Hypotheses

- H1. There will be acceptable test-retest reliability ($ICC \geq .60$) in verbal memory composite scores over three test administrations (baseline, 45 days, 50 days) among physically active individuals.
- H2. There will be acceptable test-retest reliability ($ICC \geq .60$) in visual memory composite scores over three test administrations (baseline, 45 days, 50 days) among physically active individuals.

H3. There will be acceptable test-retest reliability ($ICC \geq .60$) in motor processing speed scores over three test administrations (baseline, 45 days, 50 days) among physically active individuals.

H4. There will be acceptable test-retest reliability ($ICC \geq .60$) in reaction time composite scores over three test administrations (baseline, 45 days, 50 days) among physically active individuals.

H5. There will be no difference in test takers' effort level as measured by the Rey's 15-item memory test over three test administrations (baseline, 45 days, 50 days).

Limitations

The limitations of this study will include: 1) participants will be physically active individuals who satisfy the ACSM recommendations, 2) the participants will be college students; therefore the results may not be applicable for the other age groups; 3) the results of this study will largely depend on the effort level of participants on the neurocognitive tests.

Assumption and Delimitations

This study will make the following assumptions: 1) the participants will perform to the best of their ability on the ImPACT tests at all three testing administrations; 2) the Rey-15s Test will detect the effort level of participants on the ImPACT tests.

Definitions

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)—a computerized neuropsychological test battery, for measuring attention and processing speed in athletes with concussions (Iverson et al., 2005)

Impulse Control Composite Score—score represents the total number of errors of omission or commission on the go/no-go test and the choice reaction time test, which is used to identify

athletes who are seriously confused about test instructions or who might have made numerous right-left confusion errors (Iverson, Lovell, & Collins, 2005)

Intraclass correlation coefficient (ICC)—a univariate measure estimate of the agreement between scores on the same test at two points in time (Broglia et al., 2007)

Loss of consciousness—a state of brief coma in which the eyes are typically closed and the athlete is unresponsive to external stimuli (Lovell, 2009).

Physically active individual—individual who meets basic recommendation on cardiorespiratory, resistance, and neuromotor exercises from the American College of Sports Medicine (Garber et al., 2011)

Post Concussion Symptom Scale— the total score derived from the measurement on 22 commonly reported symptoms (e.g., headache, dizziness, “fogginess”) by seven-point likert scale (Lovell & Collins, 1998)

Post traumatic amnesia—the period of amnesia following the injury until the athlete regains normal continuous memory functioning (Lovell, 2009)

Processing Speed Composite Score— the composite score represents the weighted average of three tasks that are done as interference tasks for the memory paradigms (Iverson, Lovell, & Collins, 2005).

Reaction Time Composite Score— the composite score represents the average response time (in milliseconds) on a choice reaction time, a go/no-go task, and the previously mentioned symbol match task (Iverson, Lovell, & Collins, 2005).

Verbal Memory Composite Score— the composite score that represents the average percent correct for a word recognition paradigm, a symbol number match task, and a letter memory task with an accompanying interference task (Iverson, Lovell, & Collins, 2005).

Visual Memory Composite Score— the composite score is comprised of the average percent correct scores for two tasks; a recognition memory task that requires the discrimination of a series of abstract line drawings, and a memory task that requires the identification of a series of illuminated X's or O's after an intervening task (mouse clicking a number sequence from 25 to 1) (Iverson, Lovell, & Collins, 2005).

CHAPTER II

LITERATURE REVIEW

Introductory

Although the literature covers a wide variety of aspects regarding sports-related concussion, this review will focus on seven main areas in order to explore the current knowledge base of concussion and how computerized neurocognitive test battery has been utilized as a part of multi-facet management of this complex injury. This literature review will support the rationale of examining the test-retest reliability of a computerized neurocognitive testing battery. The review will start with a historical overview of definition and epidemiology of concussion, followed by pathophysiology, signs and symptoms, evaluation and management, overview of neuropsychological testing for concussion, and finally an overview of test-retest reliability and validity of computerized neurocognitive test batteries.

Historical Overview of Definitions

The study of brain damage has a long history. The physicians of the Hippocratic school observed in *ca.* 400 B .C that an incised wound in one temple produces a spasm in the opposite side of the body (Chadwick & Mann, 1950). The term “concussion” originates from the Latin stem of *concutere* (to dash together, to shake violently) or *concussus* (action of striking together) and it does not include any clinical or pathological consequences (Pearce, 2008). In the 16th century, its symptoms were first described in a systematic fashion by Berengario de Carpi and Ambrose Paré, who are often credited with popularizing the term “concussion”(Levin, Benton, & Grossman, 1982). The term *commotio cerebri* was used to describe the effects of brain injury without the presence of a skull fracture, and considered different from other traumatic effects on the cerebrum because of its little intensity and short duration (Denny-Brown & Russell, 1941).

In 1966, Congress passed the Traumatic Brain Injury Act of 1966, and the term *traumatic cerebral concussion* was introduced into federal law. Since then the term *cerebral concussion* has been used interchangeably with mild traumatic brain injury (Maroon et al., 2000).

Defining concussion has been a difficult task because of the complex nature of symptoms and cognitive impairments associated with this injury. Even though no consensus on the exact definition of sport-related concussion has been made to date, it has evolved over time as scientific researchers have been studying the nature of this injury. For example, historically, concussion involved a loss of consciousness (LOC) and it was a requirement in order for a concussion to be diagnosed. However, studies have shown that LOC is not as common as once reported (Guskiewicz, Weaver, Padua, & Garrett, 2000), with only approximately 9% of all concussions resulting in loss of consciousness. The American Academy of Neurology (AAN) defines concussion as a traumatically induced alteration in mental status (e.g., confusion, amnesia) that may or may not include a loss of consciousness (American Academy of Neurology, 1997). In 2001, the Concussion in Sport (CIS) group, a panel of medical experts including neurologists, neuropsychologists, and athletic trainers was assembled with the purpose of forming a basis of a comprehensive systematic approach for managing sports-related concussions by evaluating current literature. The first International Conference on Concussion in Sport was held in Vienna in 2001 and concluded that a concussion may or may not involve LOC. Since the inaugural conference, the CIS group has held two more conferences in Prague in 2004, and most recently in Zurich in 2008. Through the three conferences, a concussion has been consistently defined as “a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces”. After the first meeting, the CIS group published five common features of concussion that incorporate clinical, pathological, and biomechanical constructs to

supplement the definition of this injury. These defining features of sport-related concussion include: 1) concussion can be caused by direct impact to the head, face, neck, or elsewhere on the body with an “impulsive” force transmitted toward the head; 2) concussion typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously; 3) concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury; 4) concussion results in a graded set of clinical syndromes that may or may not involve LOC; and 5) concussion is typically associated with grossly normal structural neuroimaging studies (Aubry et al., 2002). These features of a concussion have been consistent through the three conferences; however, the statement regarding neuroimaging has changed slightly. In the first and second conference, there was a statement “concussion is typically associated with grossly normal structural neuroimaging studies”, which was changed to “no abnormality on standard structural neuroimaging studies is seen in concussion” in the third conference (Aubry et al., 2002; McCrory et al., 2005; 2009.).

Epidemiology of Concussion

In this section, the most recent prevalence and incident estimates for concussion in high school and collegiate athletics will be reviewed in order to identify the population at risk of sports-related concussion. Incidence of sports-related concussion has been reported through epidemiological studies that used Reporting Information Online (RIO) for high school population and National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) for collegiate population. In many studies athlete exposure (A-E), an exposure defined as one athlete playing in one game or practice, is used in order to study the actual injury rate, rather than percentages. Injury rates are a good measure of injury because of the differences in the number of players and practice sessions and games in different sports. According to the National

Federation of State High School Associations (NFHS) and NCAA, athletic participation rates continue to rise in both high school and collegiate population with 7,667,955 and 444,077 athletes competing, respectively (NFHS, 2011 & NCAA, 2011). As a result, the incidence of sport-related concussion is also expected to rise. Sports are second to motor vehicle crashes as the leading cause of traumatic brain injury (TBI), and it has estimated that 1.6 to 3.8 million mild TBIs occur in sports and recreational activities annually among people aged 15 to 24 years (Langlois, Rutland-Brown, & Wald, 2006). In the 1990's, the estimate was approximately 300,000 because only TBIs associated with LOC was included at that time (Langlois, Rutland-Brown, & Wald, 2006).

Epidemiological studies have reported several factors that influence the risk of sustaining a concussion, such as the competition level (high school vs. college), sports setting (competition vs. practice), and sex (female vs. male). The remaining portion of this section will review those epidemiological studies.

High School vs. College

Epidemiological studies have been conducted in both high school and collegiate populations. A very recent study conducted by Marar and colleagues (2012) examined injury data from a large, nationally dispersed sample of US high schools (n=100) during the 2008-2010 academic year. The researchers investigated the epidemiology of concussions in high school athletes. They utilized the High School RIO, an Internet-based sports injury surveillance system, and reported 1,936 concussions and 7,780,064 A-Es. Results of this study indicated that approximately 2.5 concussions per 10,000 A-Es occur at the high school level (Marar et al. 2012).

For collegiate population, Hootman and colleagues (2007) utilized the NCAA ISS to summarize 16 years (1988 to 2004) of injury data from 15 NCAA sports. For concussion, the

researchers found incidence rates that range from 1.7 (1988-89, 1989-90, 1992-93) to 4.1 (2000-01, 2001-02) per 10,000 A-Es. A significant finding of this study found that from the 1988-89 to 2003-04, the injury rate doubled (1.7 to 3.4 per 10,000 A-Es) with an average annual increase of 7.0% of concussions reported.

While the previous two studies examined either high school or college athletes, Gessel and colleagues (2007) examined the injury data with both populations. Athletes from 100 US high schools and 180 US colleges that used to compare the rate of concussion between high school and collegiate athletes during 2005-2006 academic year. The concussion rate was 4.7 and 6.1 per 10,000 A-Es in high school and college athletes, respectively. However, concussions represented a higher proportion of all injuries sustained in high school athletes (8.9%, 396 concussions /4,431 total injuries) compared to collegiate athletes (5.9%, 482 concussions/8,293 total injuries).

These data suggest that collegiate athletes may have slightly higher injury rates than high school athletes, but concussions most likely represent a greater proportion of injuries at the high school level. It is worth pointing out that there are differences in the access to the medical professionals between high school and college settings. The higher rate of concussions at the collegiate level may be due to the fact that collegiate settings tend to have greater access to sports medicine professionals, which lead to more opportunity to diagnose concussions rather than differences in actual number of concussions.

Practice vs. Game

Several studies have also examined concussion incidences and concussion rates in practice and competition. In general, both concussion incidence and rates were consistently higher in competition than in practice with a few exceptions. Marar et al. (2012) reported that

among 1,936 concussions reported from a nationally dispersed sample of US high schools, 1,289 (66.6%) occurred in competition while 647 (33.4%) concussions were reported during practice. In the same study, injury rate was also higher in competition (6.4 per 10,000 A-Es) than practice (1.1 per 10,000 A-Es) for all sports except cheerleading which had a higher injury rate in practice than in competition (1.2 versus 1.4 per 10,000 A-Es).

A higher concussion incidence rate in competition than practice was observed in the study of Gessel and colleagues (2007). In the high school setting, 5.3 concussions per 10,000 A-Es in competition and 1.1 concussions per 10,000 A-Es in practice were reported, whereas 10.2 concussions per 10,000 A-Es in competition and 2.8 concussions per 10,000 A-Es in practice were reported in the college setting.

While the comparison of injury rate between competition and practice was a part of outcomes in many studies, one study was conducted that specifically compared the practice and competition injury rates among high school athletes (Rechel et al. 2008). Rechel et al. (2008) found that concussions account for a greater proportion of competition injuries compared to practice injuries (12.0% vs. 5.9%, proportion ratio=2.02). This trend became evident in certain sports, especially in boys' soccer (15.6% vs. 2.3%, PR=6.94) and girls' basketball (19.0% vs. 3.3%, PR=5.83). The researchers thought this trend is due to the increased amount of physical contact that takes place during competition. Softball and volleyball players were the only exceptions to this trend. In softball and volleyball, concussions constituted a greater proportion of practice injuries than competition injuries (PR=.05: 95%CI=.01-.44 for softball, PR=.36: 95%CI=.06-2.24 for volleyball).

Type of Sports

Regardless the competition level and sports setting, certain sports have been identified as

high risk sports for concussion in terms of: higher number of concussion incidence, higher concussion rates, and greater proportion that concussion represents in total injuries across various sports. Of all sports played in the United States, football consistently is associated with the greatest number of sports-related concussion (ie., prevalence of concussion) at the high school and college levels, ranging from almost 50% to as high as nearly 75% of total concussions reported (Hootman, Dick, & Agel, 2007; Lincoln et al., 2011). Moreover, between the 1982 to 1983 season and the 2007 to 2008 season, a total of 35,641,573 high school athletes and 1,929,069 collegiate athletes competed in American football (Cantu & Mueller, 2009). Considering the intensity of football, as well as the fact that football has the largest number of participants, it is not surprising that football has the highest number of concussions in both high school and collegiate settings.

In the college setting, Hootman and colleagues (2007) reported 9,150 concussions over a 16-year period through the NCAA ISS, and fall football accounted for 48.1% of total concussions (4404/9150). They also reported that spring football was associated with the second greatest number of concussions (612/9150) followed by women's soccer (593/9150), men's ice hockey (527/9150), and men's soccer (500/9150). Even though women's ice hockey had the highest injury rates (9.1 concussions per 10,000 A-Es), only 79 concussions were reported, which accounted for 0.9% of the total concussion reported.

In the high school setting, Marar and colleagues (2012) reported 1,936 concussions with 47.1% (912/1936) of the total concussions occurring in football, followed by girls' soccer (8.2%, 159/1936), boys' wrestling (5.8%, 112/1936), and girls' basketball (5.5%, 107/1936). No concussions were reported from boys' volleyball. However, sports high in actual number of concussions does not necessarily mean those sports have a higher risk of concussion than other

sports. Therefore, injury rate must be compared to discuss the risk of concussions across the sports.

In terms of injury rate, several studies have suggested that women's ice hockey has the highest injury rate of concussion at the college level (9.1 per 10,000 A-Es) (Gessel, Fields, Collins, Dick, & Comstock, 2007; Hootman et al., 2007; Lincoln et al., 2011). However, it must be noted that the NCAA ISS data collection for women's ice hockey began in 2000 to 2001 and was only studied over a 3 year period while the other sports were studied over a 16 year period. This may be a reason for the higher injury rate as well as the increased awareness of concussion and improvement in diagnosis of concussion. In fact, the number of concussions reported was 79 and it was the second lowest among the all sports studied. If women's ice hockey is excluded, in the college setting, spring football had the highest incidence rate (5.4 concussions per 10,000 A-Es) followed by men's ice hockey (4.1) and women's soccer (4.1), and in-season football (3.7) (Hootman et al., 2007). It is worth mentioning that even though approximately 8 times more concussions were reported from in-season football compared to ice hockey (4,404 vs. 527), the incidence rate was higher in men's ice hockey compared to in-season football (3.7 vs. 4.1). In high school, football had the highest concussion rate with 6.4 concussions per 10,000 A-Es, followed by boy's ice hockey (5.4), and boys' lacrosse (4.0) (Marar, McIlvain, Fields, & Comstock, 2012). It must be noted that even though the total number of concussions reported from boy's ice hockey was only the seventh highest, the injury rate was the second highest after football.

The total number of injuries varies across sports, which provides another insight into the epidemiology of concussion. At the high school level, concussions represented the greatest proportion of total injuries among boys' ice hockey (22.2%) followed by girls' lacrosse (21.1%),

cheerleading (20.3%), and football (number was not given but estimated around 17% from graph) (Marar et al., 2012). In the collegiate setting women's ice hockey (18.3%) was followed by men's ice hockey (7.9%), women's lacrosse (6.3%), and in-season football (6.0%) (Hootman et al., 2007). Along with the aforementioned caution regarding the data collection for women's ice hockey, it must be noted that Marar et al. (2012) did not include women's hockey in their data collection. By contrary, cheerleading, ranked third in the study by Marar et al. (2012) was not studied in the study by Hootman et al. (2007).

When concussion data were compared across studies, the type and number of sports studied become an important factor, which is a limitation for those studies that included only sports that have relatively high concussion rates. The data from both studies of Gessel et al. (2007) and Rechel et al. (2008) were limited to five boys' sports: football, soccer, basketball, wrestling, and baseball, and four girls' sports: soccer, volleyball, basketball, and softball. The study by Marar et al. (2012) revealed that the concussion rates in boys' ice hockey and lacrosse, and girls' lacrosse were higher than the concussion rates in all the sports studied by Gessel et al. (2007) and Rechel et al. (2008), excluding football. Also, the sports that have relatively low concussion rate, such as swimming and diving, track and field, and gymnastics tend to be omitted from studies. In order to obtain accurate epidemiological data for practice and competition, researchers should not limit the study samples to athletes in major sports.

Sex Difference in Concussion Incidences

Title IX as part of the Equality in Education Act of 1972 triggered significant increase for women to participate in sports, and its rise in participation is continuing. NCAA reported between 1988 and 2004, women's participation in sports increased by 80% while men's participation increased by only 20% (Hootman et al., 2007). During the 2010-11 academic year,

191,131 female athletes participated in NCAA sports (NCAA, 2011). In the high school setting, NFHS reported that girls' participation in the 2010-11 academic year was 3,173,549, which was a record-breaking number. In addition this number represents a more than tenfold increase from the 1971-72 academic year (NFHS, 2012). This increase in participation numbers resulted in increased incidence of sports-related injuries in women, including concussion.

Epidemiological studies have been conducted in order to understand differences between female and male athletes with respect to injury incidence, severity, and mechanism. Although a significant debate exists over the influence of sex on incidence and severity of brain injuries, general trends have shown that women are at a greater risk for sustaining concussions compared to men (Covassin, Swanik, & Sachs, 2003a; Gessel et al., 2007; Hootman et al., 2007; Marar et al., 2012).

During the 2 year study period of Marar et al. (2012), 1,432 concussions were reported from boys' sports with an injury rate of 3.1 per 10,000 A-Es, and 504 concussions were reported from girls' sports with an injury rate of 1.6 per 10,000 A-Es. It must be noted that more than 60% of concussions in boys' sports were from football, which was the highest injury rate (912 concussions with 6.4 per 10,000 A-Es). However, when the data were summarized into sex comparable sports: soccer, basketball, baseball/softball, swimming and diving, and track and field, girls' sports yielded more incidences of concussions as well as higher injury rates (336 vs. 235, 1.7 vs. 1.0 concussions per 10,000 A-Es).

The same trend was reported in the previously mentioned epidemiology study conducted by Gessel and colleagues (2007). They reported that for the sports played by both sexes, girls' sports had a higher rate of concussions and represented a greater proportion of total injuries than boys (soccer: 3.6 vs. 2.2 concussions per 10,000A-Es and 21.5% vs. 15.4%; basketball: 2.1 vs.

0.7 concussions per 10,000 A-Es and 9.5% vs. 2.81%; softball/baseball: 0.7 vs. 0.5 concussions per 10,000 A-Es and 5.5% vs. 2.9%).

A recent study by Lincoln et al. (Lincoln et al., 2011) examined the incidence and relative risk of concussions. The researchers gathered injury data from 25 high schools in a large public school system over an 11 year period (1997-2008) for 12 high school boys' and girls' sports. During the 11 year period, 2,651 concussions were reported with 1,986 concussions from boys' sports, and 665 concussions from girls' sports. However, similar to what the other studies have reported, when the data was summarized into sex comparable sports, girls had a higher rate of concussion than their counterpart with the ratio of 2.1 in soccer, 1.7 in basketball, and 1.9 in softball/baseball. Lacrosse was the only exception, in which girls had a lower concussion rate compared to boys (2.0 vs. 3.0 per 10,000). The researchers thought this exception is due to the different rules, protective equipment, and nature of play between boys' and girls' game. These data suggest the presence of sex differences in the risk of concussion at the high school level, with female athletes having a higher risk of sustaining a concussion. These sex differences have also been explored in collegiate populations.

Covassin et al. (2003a; 2003b) examined injury data from NCAA ISS to compare sex differences in the incidence of concussions among collegiate athletes during the 1997-2000 academic years. During the 3 academic years, 304 concussions were reported from women's sports and 254 concussions were reported from men's sports. They found that concussions represented a greater portion of total injuries for the women's sport when they were compared with their male counterpart: lacrosse (13.9% vs. 10.1%), soccer (11.4% vs. 7.0%), and basketball (8.5% vs. 5.0%) (Covassin et al., 2003b). Also, for these three sports, female athletes were found

to be at a greater risk for sustaining a concussion during games than male athletes (Covassin et al., 2003a).

Similar results were reported from a study conducted by Hootman et al. (2007), which summarized 16 years of NCAA injury data in order to identify modifiable risk factors. The researchers reported a greater percentage of total injuries and higher injury rates in women's sports compared with their male counterpart: lacrosse (6.3% vs. 5.6%, 2.6 vs. 2.5 concussions per 10,000 A-Es), soccer (5.3% vs. 3.9%, 4.1 vs. 2.8), basketball (4.7% vs. 3.2%, 2.2 vs. 1.6), and softball/baseball (4.3% vs. 2.5%, 1.4 vs. 0.7). The data clearly suggest that female athletes have a higher risk of sustaining concussions compared to male athletes.

There are several possible reasons for these sex differences. Females have smaller head mass and weaker dynamic stabilization of the neck and head compared with males (Mansell, et al., 2005; Tierney et al., 2005; Tierney et al., 2008). Less head mass and neck strength should result in greater head accelerations upon force application based on Newton's second Law of Motion ($F=ma$); therefore, researchers have proposed strengthening the neck muscles as a method for decreasing the risk of sustaining concussions (Cross & Serenelli, 2003; Viano, Casson, & Pellman, 2007).

Major limitations of the previous epidemiology studies are (1) number and type of sports included, which has been previously mentioned and (2) reliability of using AE. Researchers need to be careful when they use AE especially in high-contact sports such as football because the chance of sustaining a concussion will be different between a full contact practice and a walk through practice even though they might be counted equivalently as one practice. Finally, it is also worth mentioning the underreported nature of this injury. Many individuals including athletes suffering from mild or moderate traumatic brain injury do not seek medical advice. For

example, a study reported that 47.3% of high school football players confidentially reported their symptoms after a blow to the head due to the reasons such as: 1) a player thinking the injury was not serious enough to seek medical care, 2) motivation to stay in competition, and 3) lack of awareness of the symptoms of concussion (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). Therefore, the published epidemiological data for sport-related concussion are thought to be a conservative estimate (Langlois et al., 2006; McCrea et al., 2004).

Pathophysiology

Dynamic loading caused by either direct impact to the head or a sudden movement of the head produced by an impact elsewhere causes acceleration forces that can damage the brain, which is the most common mechanism of head injury (Almasi & Wilson, 2012). The underlying injuries resulting from head trauma can be classified into the primary injury, which is a result of the direct mechanism at the time of incident, and the secondary injury, which is combination of systemic extracranial insults and intracranial physiological and biomechanical changes (Giza & Hovda, 2001). In this section, the secondary injury, specifically the neurometabolic cascade following concussion is reviewed.

A complex cascade of ionic, metabolic, and physiologic events occurs immediately after cerebral concussion. The primary elements are: binding of glutamine to the N-methyl-D-aspartate (NMDA), neural depolarization, abrupt ionic imbalance, increased triphosphate production adenosine (ATP) demand, and cellular-energy crisis (Giza & Hovda, 2001). Glutamine is the most abundant neurotransmitter in the brain and NMDA is negatively associated with neurological outcome in the animal model (Blaylock & Maroon, 2011; Greve, & Zink, 2009). Binding of glutamine to NMDA results in further depolarization of neurons with the efflux of potassium and influx of calcium (Giza & Hovda, 2001). The neuronal cell damage from

excessive release of excitatory neurotransmitters is called excitotoxicity. Generation of high levels of reactive oxygen species (ROS) and reactive nitrogen species (RNS), lipid peroxidation products (LPPs), prostaglandins, and nitric oxide (NO) are involved in the process of excitotoxicity, which is associated with microtubule dysfunction, membrane injury, dendritic retraction, synaptic loss, mitochondrial dysfunction, calcium dysregulation, and apoptosis (Blaylock & Maroon, 2011).

Calcium dysregulation plays a major role in excitotoxicity because calcium affects a wide range of cellular functions. High mitochondrial calcium may result in swelling, depolarization, and loss of function (Verweil et al., 2000) while the accumulation of calcium worsens the energy crisis and even lead to cell death (Giza & Hovda, 2001). Generation of ROS and decreased mitochondrial respiratory capacity may be caused by increased intracellular calcium (Nicholls, 2008). Abnormalities in calcium homeostasis may last as long as 30 days after traumatic brain injury (Sun et al., 2008).

To restore the ionic balance, the sodium-potassium pump needs to work overtime requiring increased amount of ATP, which leads to increased glucose metabolism. The need for ATP is compromised by a decrease in cerebral blood flow that is from cerebral vasoconstriction due to increased sympathetic outflow to the cephalic vasculature following the fluid-percussion brain injury (Shibata, Einhaus, Schweitzer, Zuckerman, & Leffler, 1993). This tenuous equilibrium between brain healing and the need for increased blood flow and glucose is called “concussion penumbra”(Grady, 2010). Imbalanced glucose supply and demand also cause cellular energy crisis. Along with impaired autoregulation and reactivity to vasomotor agents of the brain, cellular energy crisis is a mechanism for the brain’s vulnerability to injury following an initial trauma (Giza & Hovda, 2001).

Signs and Symptoms of Concussion

Common signs and symptoms of concussion have been discussed in sports-related concussion literature. The signs and symptoms of concussion typically fall into 4 categories: physical, cognitive, emotional, and sleep disturbances (Almasi & Wilson, 2012). Common physical symptoms reported by concussed athletes include: headache, nausea, dizziness, fatigue, vomiting, balance problems, and sensitivity to light and noise (Barth et al., 1989; Cantu, 1998a; Maddocks & Dicker, 1989). Mental foggiess, difficulty in concentrating, decreased processing speed, and memory difficulties are common cognitive symptoms (Maruta, Lee, Jacobs, & Ghajar, 2010). In addition to physical and cognitive symptoms, concussed athletes may experience personality change, sadness, nervousness, and sleep disturbance (Guskiewicz et al., 2006; Lovell et al., 2006; McCrory et al., 2005). Of all the common concussion symptoms, headache is the most common symptom, with frequency between 40% and 86%, followed by fatigue, feeling slowed down, drowsiness, and cognitive problems (Fazio, Lovell, Pardini, & Collins, 2007). According to the American Academy of Neurology, some of the signs and symptoms may last only minutes to hours (i.e., headache, dizziness and poor balance, nausea, vomiting); whereas, other signs and symptoms may last days to weeks (i.e. anxiety and nervousness, irritability, difficulty concentrating and remembering, disorientation, fatigue, light-headedness, light sensitivity, tinnitus).

For many years, LOC and post traumatic amnesia (PTA) have been used as major on-field markers for concussion (McCrea, Kelly, Randolph, Cisler, & Berger, 2002), and most of the grading scales used to determine grade and severity of concussion were based on these two symptoms. LOC can be described as paralytic coma (Ommaya & Gennarelli, 1974), and represents a state of brief coma in which the eyes are typically closed and the athlete is

unresponsive to external stimuli (Lovell, 2009). PTA may be associated with loss of memory for events either preceding or following injury, which determines the amnesia as either retrograde or anterograde amnesia (Lovell, 2009). PTA is common following LOC and sometimes occurs even without LOC (Kelly, 2001). Historically, LOC and PTA have been a key component of concussive injury. However, studies have shown that LOC and PTA may not be present in concussion as often as it was once thought, and their role and significance in the detection and management of concussion have changed. Guskiewicz and colleagues (2000) found that among 1,003 diagnosed concussions in college and high school football players, only 8.9 % and 27.7% of concussions were associated with LOC and PTA, while headache was associated with 86% of concussions, followed by dizziness (67%), confusion (59%), and disorientation (48%).

In addition to the lower prevalence of LOC and PTA, researchers have also found that LOC and PTA have weak association with other signs and symptoms of concussion. Collins et al. (1999) compared neurocognitive performance between groups of concussed patients: those who experienced LOC at the time of injury, no LOC, or uncertain LOC. The results indicated that regardless of the presence of LOC at the time of injury, all patients demonstrated poor neurocognitive performance, and no significant difference across LOC groups. Furthermore, Guskiewicz et al.(2001) assessed postural stability and neurocognitive function of 36 concussed collegiate football athletes using the Sensory Organization Test, the Balance Error Scoring System, and various neuropsychological tests: Trail-Making Test, Wechsler Digit Span Test, Stroop Color Word Test, and Hopkins Verbal Learning Test. The results indicated that LOC and PTA were not associated with increased deficits or slowed recovery on measures of postural stability or neurocognitive function. Moreover, the most recent consensus statement from the International Conference on Concussion in Sport stated that the presence or duration of PTA

alone may not be as important as the status of the clinical post-concussive symptoms. Also, the significance of LOC was not referred to as exhibiting it or not, rather in its duration (if it is >1 minutes) that may result in modifying management (Mccrory et al., 2008).

In addition to the importance of post-concussive symptoms that were pointed out in recent consensus statements, several studies have followed the post-concussive symptoms longitudinally. Studies found that different signs and symptoms recovered in different manners, but the trend has not been conclusive. One study with high school football players found that memory impairment often lasted up to 10 days post injury while other cognitive functions, reaction time, and processing speed, returned to baseline level on approximately 6 days post injury (Sim, Terryberry-Spohr, & Wilson, 2008). Another study found that the concussed athletes were asymptomatic at day 7 post injury even though verbal memory, motor processing speed, and reaction time were still impaired (Covassin, Elbin, & Nakayama, 2010). Covassin et al. (2010) also found that reaction time took the longest to return to baseline levels (up to 21 days) while memory function needed the longest recovery time in the study by Sim et al.(2008) (10 days).

Another research effort was made to predict prognosis of concussion from initial post-concussion signs and symptoms. Lau and colleagues (2012) examined the injury data of 108 male high school football athletes in order to determine cutoff scores of symptom clusters derived from the Post-Concussion Symptom Scale and a neurocognitive test scores (Immediate Post-concussion Assessment and Cognitive Testing: ImPACT) that will predict a protracted recovery (>14 days) in concussed athletes. They found statistically significant cutoff scores for migraine cluster, cognitive cluster, visual memory, and processing speed at 75%, 80%, and 85%

sensitivity to predict protracted recovery. Moreover, migraine cluster includes headaches and dizziness and the cognitive cluster includes fatigue, which is consistent with other researchers.

A cohort study by Collins et al. (2011) was similarly designed with the same population as Lau et al. (2012), but used only on-field signs and symptoms as predictors for a protracted (>21 days) versus a rapid (<7 days) recovery in concussed high school football players. On-field signs and symptoms included: headache, fatigue, confusion, LOC, PTA, imbalance, visual problems, personality changes, sensitivity to light and noise, numbness, vomiting, and dizziness. The researchers found that only on-field dizziness was associated with increased risk of a protracted recovery (OR=6.34).

A similar study was conducted in National Hockey League (NHL) players. Benson et al. (2011) conducted a prospective longitudinal study during the 1997-98 to 2003-04 seasons to examine the relationship between initial post-concussion signs and symptoms and time loss. There were 559 physician-diagnosed, regular season, in-game concussions during the seven years of study. The researchers found that headache and fatigue were significant predictors of time loss of more than 10 days (odds ratio: 2.17 and 1.72, respectively). Even though they did not reach the statistical significance at the 10 day cut-point, presence of amnesia and abnormal neurologic examination (i.e. cerebellar examination, tandem gait, rhomberg, etc.) were significant predictors of time loss. The data suggest that some signs and symptoms may be worth more attention than others in order to predict prognosis of concussion. However, when you consider the number of research studies that have investigated how to diagnose concussions, very little research has examined predicting prognosis in concussed athletes. Thus, more research with different population and standardized methods are warranted to determine more accurate prediction in concussion prognosis.

Efforts have been made to increase concussion awareness and knowledge. For example, in 2005, the CDC launched the *Heads UP* program to help educate youth coaches, high school coaches, parents, athletes, school administrators, and medical professionals, and its effectiveness has been reported (Covassin, Elbin, & Sarmiento, 2012; Sarmiento et al., 2010). Covassin and colleagues (2012) reported that the *Heads Up* material improved 77% of youth sports coaches' ability to identify athletes who may have a concussion, and made 63% of youth sports coaches view concussions as being more serious. In another study, Sarmiento et al. (2010) reported that even though most of the coaches who responded to their survey study had more than 10 years of experience coaching, more than one third (34%) of coaches reported that they learned something new about concussions from the material. Also, 82% of coaches who implemented the materials to educate athletes reported that the materials were very or extremely useful. These results are significant because sport coaches may play an important role in detecting concussion as sports medicine professionals may not always be present, especially at youth and high school settings. The sports medicine professionals are responsible for detecting, evaluating, and managing concussed athletes; however, cooperation from athletes and coaches is imperative for the best result.

A significant amount of effort have been made to improve the management of concussed athletes. These efforts will be truly rewarded when detection of concussion is improved as well. However, even though self-report from athletes is a key component of detecting probable concussions, the underreported nature of concussion has been reported (McCrea et al., 2004). McCrea and colleagues (2004) reported that 47.3% of high school football players did not report their symptoms after a blow to the head due to lack of knowledge about signs and symptoms of concussion as well as motivation to stay in competition. Therefore, athletes may hide their signs

and symptoms of a concussion or may not be sufficiently aware of the signs, symptoms, and potential catastrophic effects of concussion.

Detecting, evaluating, and managing concussed athletes is essential to prevent more serious consequences. Second-impact syndrome (SIS) is described as diffuse cerebral swelling leading to the rapid development of cerebral vascular congestion, which in turn causes increased intracranial pressure that often results in brainstem herniation and death (Cantu, 1998). Although very rare, SIS can occur if a concussed individual sustains a second head injury before their first concussion fully resolves (Cantu & Voy, 1995; Cantu, 1998). A recent study analyzed the 30-year (1980-2009) US National Registry of Sudden Death in Young Athletes, and reported 17 deaths of high school athletes who sustained a concussion shortly before fatal head trauma (SIS) (Thomas et al., 2011).

There has been a claim that the term “second-impact syndrome” is misleading and the syndrome should be referred to as “diffuse cerebral swelling” (McCrory, 2001; McCrory, Davis, & Makdissi, 2012). There are several possible reasons for this rationale. First, the evidence for SIS is all anecdotal case reports. Second, all 17 cases were reported in North America and no case have been reported from other countries. Third, the brain of SIS patients often accompanies a subdural hematoma, which is a structural injury. Lastly, no clear link between “second” impact to death is established (McCrory et al., 2012). Further debate is expected. However, regardless what the syndrome is called, there is a vulnerable window after the initial head trauma due to metabolic dysfunction as was previously mentioned in the pathophysiology section of this review of literature. Therefore, the early detection and proper management of sports-related concussion are essential to reduce the risk of catastrophic consequences.

Evaluation and Management of Sports-Related Concussion

Due to concussions' complex nature, the evaluation, management, and return to play decisions are one of the biggest challenges for sports medicine professionals. Over the past two decades, approximately 20 management guidelines have been published, which are largely based on the opinions of groups of experts rather than on systematic research (Collins, 1999). However, as a result of reevaluation and revision of prior guidelines through empirical studies, the management and return to play strategies for sports-related concussion have been refined. Specifically, the utilization of computerized neurocognitive test batteries, imaging techniques, and individualized management recommendation have been incorporated in new management guidelines. Furthermore, consensus statements have suggested the abolishment of historically utilized concussion grading scales. In this section, both historical and current management guidelines will be reviewed.

Historically, the severity of concussion has been assessed by grading or assigning a numerical value such as Grade 1 (mild), Grade 2 (moderate), and Grade 3 (severe), and the majority of return to play guidelines corresponds to the grading system. Clinicians suggested grading scales to unify the concussion management. However, researchers have criticized this uniformed management for several reasons, including lack of consensus, over-reliance on LOC as a primary marker of severity, inability to account for individual difference in recovery rate and symptom presentation, and lack of empirical support (Aubry et al., 2002; Collins, 1999; Kelly, 2001; McCrory et al., 2005). However, the common grading and return to play guidelines are still worth being reviewed as they are important part of the history of concussion management guidelines.

The AAN (1997), Cantu's Grading Scales (1986; 2001), and the Colorado Medical Society Guidelines (1994) have become the most recognized guidelines in sports-medicine professionals. All three grading scales have LOC and PTA as the primary markers of concussion, although the duration of LOC and PTA differs across the guidelines. The grading scales are summarized in Table 1.

Typically grading scales also have their own return to play guidelines that are based on their grading system (see table 2). It must be noted that the AAN, Cantu's, and Colorado Medical Society Guidelines permit mildly concussed athletes to return to the same game/practice if they did not experience any LOC or PTA, the symptoms are resolved on the sideline within 15 minutes, and they successfully complete all sideline mental assessments. In addition to the study that reported the low prevalence of LOC and PTA in concussion (Guskiewicz, Weaver, Padua, & Garrett, 2000), and their weak association with other signs and symptoms of concussion (Guskiewicz, 2001; Collins et al., 1999), studies have questioned the return to play guidelines that are based on the grading systems over-reliance on LOC and PTA.

Leiniger et al. (1990) compared neuropsychological outcomes between minor head injury patients with and without LOC in order to investigate the relative impact of LOC on the development of neuropsychological dysfunction after head injury. The researchers administered eight neuropsychological tests to patients who were assigned into 3 groups based on their level of consciousness immediately after the injury: patients who experienced LOC (concussion group, n=31), patients who experienced disorientation or confusion but no LOC (mild concussion group, n=22), and a demographically matched control group (n=23). No significant difference between concussion group and mild concussion group were found on any of the tests, while mild concussion group scored significantly poorer than the controlled group on five of the eight tests.

This study suggested that LOC has no impact on distinguishing patients at greater or reduced risk for neuropsychological outcomes.

Similarly, Lovell et al. (1999) reported the failure to find any relationship between LOC and neuropsychological function in their study with 383 concussed patients who were assigned to: LOC, no LOC, and uncertain LOC groups based on their level of consciousness at the time of injury. Neuropsychological tests, including the visual reproduction, digit span, and logical memory subtests of the Wechsler memory scale, the Trail Making test, Wisconsin Card Sorting test, Hopkins Verbal Learning test, Controlled Oral word Association, and the Galveston Orientation and Amnesia test were administered. While mildly decreased performance on speed of information processing, attention process, and memory in all three groups were observed, no significant differences were found between the groups in any of the test results. The results of this study added more evidence to the question on the significance of LOC as a predictor of severity of concussion.

While the presence of LOC as a predictor of concussion severity has been questioned, Collins et al. (2003) found that the presence of amnesia is predictive of symptoms and neurocognitive deficits following concussion. A total of 78 concussed athletes were assigned into good post-injury presentation group (no measurable change relative to baseline, n=44) and poor post-injury presentation group (10 point increase in symptom reporting and 10 point decrease in memory functioning, n=34) based on ImPACT memory and symptom composite scores 2 days after injury. The value of on-field disorientation, PTA, retrograde amnesia, and LOC was evaluated as predictor variables for determining whether the concussed athletes fall into good or poor post-injury presentation group. The results showed that athletes who exhibited retrograde amnesia and PTA were over 10 and 4 times more likely to demonstrate poor presentation,

respectively. On the other hand, experience of LOC or brief disorientation (<5 minutes) did not predict the presentation group. The result of this study indicated that refinement of sports concussion grading scales that heavily rely on LOC is necessary.

In addition to the researches that questioned the usage of LOC to determine and predict the severity of sports-related concussions, Lovell et al. (2004) evaluated a commonly used grading scale itself, not its components, in terms of the athletes' neurocognitive functions measured by a computerized neuropsychological testing battery (ImPACT). The researchers followed the neuropsychological functions of high school athletes with Grade 1 concussions during the first week of recovery. A series of ImPACT tests were administered to 43 athletes diagnosed with a Grade 1 concussion based on AAN grading scale at 36 hours and 6 days post-injury to compare to preseason baseline testing. At 36 hours post-injury, statistically significant decline in memory ($P < .003$) and increase in self-reported symptoms ($P < .00001$) compared to baseline performance were observed. Also, even though statistically non-significant, subtle declines on reaction time and processing speed at 36 hours post-injury were reported. At the second follow up, no significant difference in memory compared to the baseline, and significantly fewer symptoms than the first follow up were reported. This study suggested that the return to play guideline for Grade 1 concussion accompanies the risk of premature return.

Table 1. Grading system from AAN (1997), Cantu (1986&2001), and CMS (1994)

Guideline	Severity of Grade		
	1 (mild)	2 (moderate)	3 (severe)
Cantu (1986)	(1) No LOC	(1) LOC < 5 min	(1) LOC > 5 min
	(2) PTA < 30 min	OR	OR
		(2) PTA > 30 min	(2) PTA > 24 hrs
Cantu Revised (2001)	(1) No LOC	(1) LOC < 1 min	(1) LOC > 1 min
	(2) PTA* or post- concussion signs and symptoms < 30 min	OR	OR
		(2) PTA* > 30 minutes, but < 24 hrs	(2) PTA* > 24 hrs
			OR (3) Symptoms > 7 days
CMS	(1) Confusion without amnesia	(1) Confusion with amnesia.	(1) LOC (any duration)
	(2) No LOC	(2) No LOC	
AAN	(1) Transient confusion	(1) Transient confusion	(1) LOC (brief or prolonged)
	(2) No LOC	(2) No LOC	
	(3) Concussion symptom or mental status change resolves in < 15 min.	(3) Concussion symptom or mental status change resolves in > 15 min.	

*retrograde or anterograde

Table 2. Return to play guideline from AAN (1997), Cantu (1986&2001), and CMS (1994)

Guideline	Severity of Grade		
	1(mild)	2(moderate)	3(severe)
Cantu (1986)	Athlete may return to play that day in select situations if normal clinical examination at rest and exertion. If symptomatic, athlete may return to play in 7 days.	Athlete may return to play in 2 wks if asymptomatic at rest and exertion for 7 days.	Athlete may return to play in 1 mo if asymptomatic at rest and exertion for 7 days.
Cantu Revised (2001)	1st concussion: Return to play if asymptomatic for 1wk 2nd concussion: Return to play after asymptomatic for 1wk 3rd concussion: Minimum of 1 month; may return to play if asymptomatic for 1wk	1st concussion: Return to play in 2 wks if asymptomatic for 1wk 2nd concussion: Minimum of 1mo; may return to play if asymptomatic for 1wk; consider terminating season 3rd concussion: Terminate season; may return to play next season if asymptomatic	Terminate season; may return to play next season if asymptomatic
CMS	Remove athlete from contest and evaluate immediately and every 5 min. Permit athlete to return if amnesia or symptoms do not appear for 20 min.	Remove athlete from contest and disallow athlete to return. Permit athlete to return to practice after 1 wk if asymptomatic.	Transport athlete to hospital. Perform neurological examination and observe overnight. Permit athlete to return to play after 2 wks if asymptomatic.
AAN	Examine athlete immediately for mental status changes. Return to contest if no symptoms or mental status changes at 15 min.	Remove athlete from game and disallow to return. Athlete can return in 1 wk if asymptomatic.	Transport athlete to hospital. Permit athlete to return to play if asymptomatic 1 wk (brief LOC) or 2 wks (prolonged LOC).

*retrograde or anterograde

Sports-Related Concussion Consensus and Position Statements

The criticism and shortcomings of concussion management guidelines have been addressed in more recent consensus papers and position statements (Aubry et al., 2002; Guskiewicz et al., 2004; McCrory et al., 2005;2009). In 2002, a group of physicians, neuropsychologists, and sports administrators organized the 1st International Conference on Concussion in Sport in Vienna, Austria. The Concussion in Sport (CIS) group discussed key elements to concussion evaluation and management in order to try and reduce the morbidity secondary to sports-related concussion. One of the most important conclusions of the meeting was that the previously published concussion management guidelines were not adequate to assure proper management of every concussed athlete (Aubry et al. 2002). Moreover, this group advocated for the abolishment of concussion grading scales.

Regarding return to play on the same day of a concussion, the CIS group concluded that the concussed athlete who is still demonstrating any signs and symptoms of concussion should not be allowed to return to play in the current game or practice regardless the presence of LOC and PTA (Aubry et al., 2002; McCrory et al., 2005; 2009). Concussed athletes not being recommended to return to play on the same day of their concussion was also agreed by the position statement of National Athletic Trainers' Association (NATA) on management of sports-related concussion (Guskiewicz et al., 2004).

The CSI and the NATA position statements similarly recommended a medically supervised step-wise return-to-play process (Aubry et al., 2002; Mccrory et al., 2005; 2009). The recommended return-to-play step-wise process following a concussion includes: 1) No activity, complete physical and cognitive rest until asymptomatic, 2) Light aerobic exercise such as walking or stationary cycling at less than 70% of predicted max heart rate, no resistance training,

3) Sport specific exercise without head impact, 4) Non-contact training drills and possible load progressive resistance training, 5) Full contact training after medical clearance, and 6) Return to play (McCrory et al. 2009). These stages are based on the possibility of symptoms returning from progressive physical and sport-specific exertion (Guskiewicz et al., 2004). Injured athletes are recommended to continue to proceed to the next level if they remain asymptomatic at the current stage. If concussion symptoms return, the athlete should go back to the previous asymptomatic stage and resume the progression after 24 hours of physical and cognitive rest (McCrory et al., 2009). Unlike the old return to play guidelines, this step-wise guideline has flexibility to respond to individual differences in recovery from concussion.

Consensus statements and position papers have stressed that sports medicine professionals should take a multidisciplinary approach when managing concussion (Guskiewicz et al., 2004; McCrory et al., 2009.). Along with objective balance assessment, neuroimaging, genetic testing, the value of neuropsychological testing in concussion evaluation and management has been shown to be effective (Meehan, d' Hemecourt, Collins, Taylor, & Comstock, 2012). Recently, a number of computerized neuropsychological testing programs have been designed, and their clinical application has become common practice. In the next section, an overview of neuropsychological tests in concussed athletes, including reliability and validity of those testing programs will be reviewed.

Overview of Neuropsychological Testing for Concussion

Neurocognitive assessment is a crucial element of multidisciplinary concussion management as it provides sports medicine professionals with objective information that cannot be obtained from self-reported symptoms and post-injury behavior. Neurocognitive assessments have also been suggested to help determine the long-term cognitive recovery from concussion

(Guskiewicz et al., 2004). Neurocognitive assessment batteries evaluate multiple aspects of cognitive function. For example, researchers have found decreases in psychomotor speed, attention and concentration, working memory, mental set shifting, information processing speed, reaction time, executive functioning, and memory after an individual incurs a concussion (Collins, 1999; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Erlanger, Kaushik, et al., 2003; Iverson, Lovell, & Collins, 2005). Researchers have also found that some cognitive functions may be more sensitive to the immediate effects of concussion than others. A meta analysis conducted by Beleaner and Vanderploeg (2005) reviewed 21 studies and 790 reported concussions in order to examine the impact of sports-related concussion across six cognitive domains: orientation, attention, executive functioning, memory acquisition, delayed memory, and global cognitive ability. Results suggested that delayed memory, memory acquisition, and global cognitive functioning were most sensitive to the immediate effects of concussion.

The pre-participation baseline assessments followed by a series of post-concussion assessments have become the current standard of concussion management. Researchers have strongly suggested to employ baseline testing as it enables the sports medicine professionals to compare the concussed athletes' current cognitive function to his/her own baseline cognitive function in order to track recovery from concussion, which makes the concussion management more individualized (Guskiewicz et al., 2004). One of the advantages of employing baseline testing is its ability to minimize possible confounding factors such as age and sex, which could exist if normative data is used. In addition, employing baseline testing allows the sports medicine professionals to take an individual's cognitive strength and weakness into account so that post injury deficits can be differentiated from pre-morbid weakness (Bernhardt, 2000). Currently, the use of baseline and serial post-concussion testing are implemented at the high school, collegiate,

and professional level as a key component of a comprehensive approach to sports-related concussion management to ensure the athletes' safe return to play.

Advancement of neurocognitive assessment for sports-related concussion from traditional paper and pencil tests to computerized neuropsychological testing enabled the use of baseline and serial post-concussion testing for large number of athletes. The rest of chapter will review the traditional paper and pencil test, and several computerized neuropsychological test batteries. In addition, sensitivity, specificity, and test-retest reliability of each test will be summarized. For purposes of this chapter, sensitivity is defined as the probability that a test result will be positive when a concussion is present, and specificity is defined as the probability that test result will be negative when a concussion is not present (Schatz, Pardini, Lovell, Collins, & Podell, 2006). Test-retest reliability is defined as the extent to which scores on the battery remain stable over time (Randolph, McCrea, & Barr, 2005).

Paper and Pencil Neurocognitive Tests

Traditional neuropsychological assessment of concussion employs paper and pencil measures. A study by Barth et al. (1989) was one of the first to prospectively assess neurocognitive performance in concussed athletes. Four paper and pencil neurocognitive tests including the Paced Auditory Serial Addition Test, the Trail-Making Test A and B, and the Digit Symbol Test were administered to approximately 2,300 college football players. The same four tests were re-administered within 24 hours, 5 days, and 10 days post injury to all concussed athletes (n=183), and 48 age-matched non-injured controls. Results showed decreases in auditory attention and visuomotor speed at 24 hours post injury in concussed athletes, however, these deficits were resolved by 5 days post injury. In spite of its limitation of including non-athletes as controls, this study was considered a hallmark study because it established the use of an athlete's

pre-season baseline levels of cognitive performance for comparison to post-concussion levels, which influenced the later sports-related concussion researchers.

After the hallmark study by Barth et al. (1989), other researchers prospectively assessed cognitive recovery from sports-related concussion. Collins et al. (1999) prospectively administered a battery of eight paper-and-pencil neurocognitive tests to 393 collegiate football players in order to evaluate post-concussion recovery. The testing battery included the Hopkins Verbal Learning Test (HVLT, verbal learning and delayed memory), the Trail-Making Tests A and B (visual scanning and executive functioning), the Digit Span Test (attention and concentration), the Symbol Digit Modalities Test (information processing speed), the Grooved Pegboard Test for dominant and non-dominant hands (bilateral fine motor speed), and the Controlled Oral Word Association Test (CWAT, word fluency). Follow-up testing was administered to 16 concussed football players within 24 hours of injury, 3, 5, and 7 days post injury. Results revealed significant impairments in verbal learning and delayed memory, and moderate declines in executive function and processing speed were found at 24 hours and 3 days post injury. Concussed athletes in this study were found to have their cognitive decrements and post-concussion symptoms return to baseline levels by 5 to 7 days and 3 to 5 days, respectively.

While paper and pencil assessments have served an important role in sports-related concussion management, some problematic issues in both clinical and research have been identified. Generally, paper and pencil assessments are time consuming and costly, and also require a trained on call clinical professional for proper administration and evaluation (Collins & Hawn, 2002). Furthermore, these assessments were susceptible to learning effects (Hinton-Bayre, Geffen, Geffen, McFarland, & Friis, 1999), and its sensitivity to concussion have been questioned when brief batteries are administered, which is common in sports medicine in order

to test the entire athletic teams (McCrea et al., 2005). Specifically, McCrea et al. (2005) reported that a brief test battery that included the Hopkins Verbal Learning Test, the Trail Making Test Parts A and B, the Symbol Digit Modalities Test, the Stroop Color Word Test, and the Controlled Oral Word Association Test was reported to be 23% sensitive to concussion when administered two days post injury. As a result of the above mentioned issues, paper and pencil assessment was replaced by computerized neurocognitive assessment program for sports related concussion management.

Computerized Neuropsychological Assessment of Concussion

In order to overcome the weaknesses in traditional paper and pencil neuropsychological assessment of concussion, several computerized neuropsychological assessment and symptom evaluation systems have been developed including the Automated Neuropsychological Assessment Metrics sports medicine battery (ASMB), CogSport, Concussion Resolution Index (CRI), and the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT). These batteries assess reaction time as well as several domains of neuropsychological function including working memory, attention, concentration, visual spatial, and short-term verbal and non-verbal memory.

There are several advantages in using computerized neuropsychological assessments over the traditional paper and pencil tests. First, the test administration, data collection, and comparison are easier than the traditional assessments. Second, computerized neuropsychological batteries offer increased alternate forms through randomization of items which decreases any learning effects. Third, test takers can complete the task more efficiently due to less frustration and stronger likelihood of engaging and maintaining interest (Schatz & Zillmer, 2003). Finally, computerized assessments are able to detect slight differences in the

patients' performance (ie., reaction time) that is not possible by a human examiner (Schatz & Zillmer, 2003). However, computerized assessments also have its disadvantages such as creating a false sense of ability that anyone can diagnose neuropsychological deficits, encouraging a passive stance rather than taking an active role in the process, and inability to assess efferent language or verbal modalities (Schatz & Putz, 2006). Despite these disadvantages, computerized neuropsychological assessments have gained popularity in the past decade and several computerized neurocognitive testing programs have been available commercially for concussion management. The rest of this section will review each computerized neuropsychological testing battery.

Automated Neuropsychological Assessment Metrics (ANAM)

ANAM is the standard clinical subset of the Office of Military Performance Assessment Technology's Tester's Workbench. It is a computer based cognitive assessment tool designed to detect the accuracy and efficiency of cognitive processing in variety of situations (Levinsons & Reeves, 1997). Test administration takes approximately 20 minutes to complete. Originally, ANAM was introduced by the US Department of Defense for military research to examine the cognitive performance of soldiers who were exposed to extreme environmental stressors or neurotoxins, such as 30 days of undersea missions, fatigue during desert storm bomber missions, and being wounded with depleted uranium bullets (Levinsons & Reeves, 1997). A study that collected neuropsychological data using ANAM from 961 soldiers pre- and post-deployment to Iraq reported that post-deployment soldiers exhibited cognitive deficits in sustained attention, verbal learning, and visual spatial memory along with significantly higher confusion and tension (Vasterling et al., 2006).

Levinson and Reeves (1997) investigated the sensitivity of ANAM in patients with acquired brain injury. Participants in this study include 22 individuals with a motor vehicle accident and two who suffered from a vascular accident undergoing a traumatic brain injury rehabilitation program. Participants had been classified as marginally impaired (n=8), mildly impaired (n=7), or moderately impaired (n=7) based on their performances on neuropsychological evaluations (Cognitive Assessment System) and observations of an individual's interactions in social settings as well as personal interviews. Then ANAM was administered two times separated by a 2 to 3 month interval to examine its ability to classify the patients by comparing with the original classification (impaired, mildly impaired, and moderately impaired). At the first administration, the results of ANAM classified 91% of the patients into groups accurately. Furthermore, classification rate was 100% when mild and moderately impaired patients were combined as one group. At the second administration, the results of ANAM classified 86.36% of the patients into groups accurately. This study revealed the ability of ANAM in distinguishing the severity of acquired head injury.

The construct validity of ANAM has been supported by a study done by Bleiberg and colleagues (2000). In this study, the relation between ANAM and a set of traditional clinical neuropsychological tests (Trail Making Test part B, Consonant trigrams total score, Paced Auditory Serial Addition test, the Hopkins Verbal Learning test, and the Stroop Color-Word test) were examined. The strongest correlation for mathematical processing (MTH), Sternberg memory procedure (STN), and spatial processing (SPD) were found with Paced Auditory Serial Addition test (.663, .447, and .327, respectively). The strongest correlation for matching to sample (MSP) was found with Trail Making Test part B (-.497). All correlations were

statistically significant at $p > 0.01$ level. This study indicated strong concordance between ANAM and traditional neuropsychological measures.

The clinical utility of ANAM goes beyond military research and is also used in a variety of illnesses including multiple sclerosis, systemic lupus erythematosus, Parkinson's disease, Alzheimer's disease, migraine headaches, and brain injuries (Kane, Roebuck-Spencer, Short, Kabat, & Wilken, 2007). ANAM-sports medicine battery is one of the multiple alternate forms of ANAM, and it consists of simple reaction time (SRT), code substitution (CDS), code substitution-delayed (CDD), continuous performance test (CPT), mathematical processing (MTH), matching to sample (MSP), spatial processing (SPD), Sternberg memory procedure (STN), and procedural reaction time (PRM) (Cernich, Reeves, Sun, & Bleiberg, 2007). Each subtest provides an accuracy score (percent correct) and a throughput score (number of correct responses per minutes).

Segalowitz and colleagues (2007) examined the test-retest reliability of ANAM sports medicine battery in a group of 29 adolescents. The researchers administered ANAM twice during the same time of day over a one week interval. The intra class correlations (ICC) and the Pearson correlation coefficient for each composite score were calculated for test-retest reliability. The highest ICC was reported in MSP (.72), followed by CPT (.65), MTH (.61), CDS (.58), SRT2 (.47), and SRT (.44). The highest Pearson correlation coefficient was reported in CDS (.81), followed by MSP (.72), CPT (.70), CDD (.67), SRT2 (.50), and SRT (.48). Even though the high throughput score was reported (.87), the results revealed the variability of test-retest reliability for individual subtests of ANAM.

Another study assessed the reliability of ANAM sports medicine battery through test-retest methods using a military sample. The average test-retest interval for this study was 166.5

days. Results revealed a wide range of ICC for each subtest with the highest ICC in MTH (.87), followed by MSP (.66), SPD (.60), CPT (.58), STN (.48), and SRT (.38) (Cernich et al., 2007). It is important to point out that in both studies, there are low ICC values reported for reaction time.

The validity and reliability of some subtests of ANAM and ANAM sports medicine battery were below the acceptable value, which is suggested to be .60 to .70 (Baumgartner & Chung, 2001). Further studies are warranted in relation to maturation issue (frequency of baseline update), effect of confounding factors such as stress, fatigue, and sleep deprivation on the test performance (Cernich et al., 2007).

CogSport

CogSport is a testing battery developed by CogState (1999) measuring psychomotor function, speed of processing, visual attention, vigilance, and verbal and visual learning and memory. The battery employs a series of “card games” to examine cognitive function: simple reaction time, complex reaction time, one-back and continuous learning. CogSport can be administered without a trained personnel and takes only approximately 15 minutes.

Collie et al. (2003) determined the reliability of CogSport measurement by calculating ICC on serial data collected in 60 healthy youth volunteers at intervals of 1 hour and 1 week. In the same study, construct validity was also determined by calculating ICC coefficients between CogSport outcome variables and performance on traditional paper and pencil assessment tools (Digit symbol Substitution test and the Trail Making Test Part B) in 240 professional athletes competing in the Australian Football League. The result showed high to very high ICC in CogSport speed indices at intervals of 1 hour and 1 week (.69-.90), while CogSport accuracy indices displayed lower and more variable ICC (.08-.51). Variety of correlation coefficient between CogSport measures and the Digit symbol Substitution test were reported with the

highest in decision making ($r=.86$), followed by working memory speed (.76), psychomotor speed (.50), and learning speed (.42). Smaller and less variable correlation coefficient between CogSport measures and the Trail Making Test Part B were observed with the highest in psychomotor speed (.44), decision making (.34), working memory speed (.33) and learning speed (.23).

Axon Sports is a recently launched company with CogState providing them with a Computerized Cognitive Assessment Tool (Axon Sports CCAT). Like CogSport, this test battery also employs a “card game” to evaluate cognitive domains including processing speed, attention, learning, and working memory. Makdissi et al. (2010) conducted a prospective study and tracked the recovery of 78 concussed male Australian football players utilizing the baseline and post concussion data of the Axon sport CCAT and traditional paper and pencil tests (the Digit Symbol Substitution Test and the Trail Making Test Part B). While concussion associated symptoms lasted an average of 48.6 hours (95% CI: 39.5-57.7 hours) and symptoms and cognitive deficits on the traditional paper and pencil test had largely resolve at 7 days post injury, 17.9% of players still displayed significant cognitive decline on the Axon sport CCAT. The longer cognitive deficits on the Axon sport CCAT compared with the traditional paper and pencil test on average 2 to 3 days was reported. This study implied greater sensitivity of Axon sport CCAT to cognitive impairment following concussion compared to the Digit Symbol substitution test and the Trail Making Test Part B.

Broglio and colleagues (2007) examined the test-retest reliability of three computerized neuropsychological testing batteries: Immediate post Concussion Assessment and Cognitive Testing (ImPACT), Concussion Resolution Index (CRI), and Concussion Sentinel, which is an earlier version of CogSport. In this study, these computerized neuropsychological test batteries

were administered successively (the order of administration was not specified) at 3 occasions with clinically relevant intervals: baseline, 45 days after baseline, and 50 days after baseline. Along with the neuropsychological testing, the Memory and Concentration Test for Windows (MACT), which is a computer-based effort assessment was administered in order to control for suboptimal effort. ICC were obtained using data from 73 participants and their demographics were as follows: age= 21.39 ± 2.78 years, height= 170.95 ± 9.00 cm, body mass= 69.09 ± 15.07 kg and total self reported SAT score = 1168.17 ± 99.76 . A history of diagnosed concussion was reported from 12 participants, and number of concussions ranged from 1 to 5. Based on 7 tasks, Concussion Sentinel develops 5 output scores: reaction time, decision making, matching, attention, and working memory. The results showed wide range of ICC. When baseline and day 45 were compared, the highest ICC was observed for working memory (.65), followed by reaction time (.60), decision making (.56), attention (.43), and matching (.23). When day 45 and day 50 were compared, the highest ICC was reported for matching (.66), followed by working memory (.64), decision making (.62), reaction time (.55), and attention (.39). The MACT implied that good effort was made by participants throughout the study. However, the effect of successively administered three neuropsychological testing batteries on the participants' performance was pointed out as a possible methodological flaw.

Concussion Resolution Index (CRI)

The CRI, developed by HeadMinder, Inc., is a web-based computerized neuropsychological assessment battery designed for sports medicine professionals who manage and monitor resolution of sport-related concussion symptoms. The CRI is comprised of six subtests: reaction time, cued reaction time, visual recognition 1 and 2, animal decoding, and symbol scanning. Symbol scanning measures simple and complex reaction time, visual scanning,

and psychomotor speed. These six subtests form three CRI indices: Psychomotor, Speed Index, Simple Reaction Time. In addition to cognitive testing, the CRI collects demographic information, medical history, concussion history, and symptom report. Test duration is approximately 25 minutes for baseline and 20 minutes for post concussion assessments.

Concurrent validity was established using traditional neuropsychological paper and pencil-based tests. Correlation for CRI Psychomotor Speed Index were 0.66, 0.60, 0.57 and 0.58 for the Single Digit Modality Test, the Grooved Pegboard Test (dominant and nondominant hand), and the WAIS-III Symbol Search subtest, respectively (Erlanger et al., 1999).

Correlations for CRI Complex Reaction Time Index were 0.59 and 0.70 for the Grooved Pegboard test for dominant and nondominant hand, respectively (Erlanger et al., 1999).

Correlations for CRI Simple Reaction Time Index were 0.56, 0.46, and 0.60 for Trail Making Test Part A, and the Grooved Pegboard Test (dominant and nondominant hand), respectively (Erlanger et al., 1999)

Erlanger et al. (2003) reported that test-retest reliabilities with a 2-week interval were .82 for psychomotor speed, .70 for simple reaction time, and .68 for complex reaction time. Erlanger et al. (2001) also examined the sensitivity of the CRI in detecting change between baseline and post concussive assessment. The CRI has a 77% sensitivity to concussion. Thus, initially the CRI was found to be a valid and reliable method of identifying changes in psychomotor speed and processing speed subsequent to sports-related concussion.

However, in a latter study by Broglio et al. (2007), the reliability of the CRI was questioned. In this study, Broglio and colleagues reported extremely low ICC (.03) for Simple Reaction Time Error score when day 45 and day 50 were compared to baseline. Low ICC were also reported for Simple Reaction Time Errors score (.15) and Complex Reaction Time Error

score (.26) when baseline and day 45 were compared. However, as it has been previously mentioned, this study may be flawed by methodological problems.

Immediate post Concussion Assessment and Cognitive Testing (ImPACT)

The ImPACT test battery evaluates multiple aspects of neurocognitive function including post concussion symptoms, attention, memory, visual motor speed, and reaction time. The ImPACT consists of three main parts: demographic data, Post-Concussion-Symptom Scale (PCSS), and neuropsychological tests. The demographic data section provides the sports medicine professionals with subjects' sport, medical history, and concussion history information. The PCSS is comprised of 22-concussion symptoms with a 7-point likert scale (0 to 6). Athletes self-report their concussion symptoms from not experiencing (0) to severely experiencing (6) the symptom. The neuropsychological tests are comprised of six modules that tests attention, concentration, working memory, visual recognition, and reaction time. From the six modules, five composite scores are generated: verbal memory, visual memory, visuomotor speed, reaction time and impulse control. Impulse control composite score is included to determinate if an athlete purposefully does not try hard on the test or makes too many errors resulting in an invalid test. Recently, an online version of the ImPACT test has been developed, which enhanced the ease of use of this assessment tool. Compared to other computerized neurocognitive tests, a larger population of clinicians and researchers have used this cognitive tool. In addition, there has been several studies conducted regarding sensitivity and specificity, reliability, and validity of ImPACT test battery.

Schatz and colleagues (2006) examined the diagnostic utility of the composite scores and the PCSS of the ImPACT in a group of 72 concussed student-athletes and 66 non concussed student-athletes. The concussed athletes primarily included football players (73%) and the

majority of the non-contact sports included athletes participating in track and field and tennis (79%). All athletes were administered a baseline or pre-injury evaluation that included an ImPACT test. All concussed athletes were tested within 72 hours of sustaining a concussion. Concussions were diagnosed by certified athletic trainers or team physicians based on the criteria of the American Academy of Neurology. Data was analyzed to measure the ability of the five ImPACT composite scores and PCSS to classify concussion status. A stepwise discriminant analysis found one discriminate function identifying PCSS, processing speed composite, visual memory composite, and impulse control composite as significant factors ($p=.0001$) with 85.5% of concussion cases correctly classified. Approximately 82% of participants in the concussion group and 89% of participants in the control group were correctly classified. Thus, the classification results revealed the sensitivity of ImPACT is 81.9% and the specificity is 89.4%.

In order to examine the construct validity of ImPACT, Maerlender et al. (2010) compared scores on the ImPACT test battery to a neuropsychological battery and experimental cognitive measures in 54 healthy male athletes. The neuropsychological battery included the California Verbal Learning test, the Brief Visual Memory Test, the Delis Kaplan Executive Function system, the Grooved Pegboard, the Paced Auditory Serial Attention Test, the Beck Depression Inventory, the Spielberger State-Trait Anxiety Questionnaire, and the Word Memory Test. The experimental cognitive measures included the N-back and the verbal continuous memory task. The following scores were generated: neuropsychological verbal memory score, neuropsychological working memory score, neuropsychological visual memory score, neuropsychological processing speed score, neuropsychological attention score, neuropsychological reaction time score, neuropsychological motor score, and neuropsychological impulse control score. The results showed significant correlations between

neuropsychological domains and all ImPACT domain scores except the impulse control factor. The ImPACT verbal memory correlated with neuropsychological verbal ($r=.40, p=.00$) and visual memory ($r=.44, p=.01$), the ImPACT visual memory correlated with neuropsychological visual memory ($r=.59, p=.00$), the ImPACT visual motor processing speed and reaction time score correlated with neuropsychological working memory ($r=.39, p=.00$ and $r=-.31, p=.02$) and neuropsychological process speed ($r=.41, p=.00$ and $r=-.37, p=.01$), and neuropsychological reaction time score ($r=.34, p=.00$ and $r=-.39, p=.00$). It must be noted that the neuropsychological domain scores for motor, attention, and impulse control were not correlated with any ImPACT composite scores. Overall the results suggest that the cognitive domains represented by ImPACT have good construct validity with standard neuropsychological tests that are sensitive to cognitive functions associated with mTBI.

While good sensitivity and specificity, and construct validity of ImPACT have been reported, its test-retest reliability has been shown to be inconsistent. Iverson et al.(2003) examined the test-retest reliability over a 7-day time span using a sample of 56 nonconcussed adolescent and young adults (29 males and 27 females, average age: 17.6 years). The participants completed the ImPACT test battery on two occasions with a 7 day interval. The researchers reported that the Pearson test-retest correlation coefficients and probable ranges of measurement error for the composite scores: verbal memory=.70 (6.83pts), visual memory=.67 (10.59pts), reaction time=.79 (.05sec), processing speed=.89 (3.89pts), and post-concussion scale=.65 (7.17pts). There was a significant difference between the first and 7 day retest on the processing speed composite ($p<.003$) with 68% of the sample performing better at the 7 day retest interval than at the first test. This study was limited by the variation of testing intervals. Specifically,

29% of the participants were retested within 3 days, 43% within 4 days, 82% within 7 days, and 95% within 11 days. Although the median was 7 days (average=5.8 days).

Miller et al. (2007) conducted a test-retest study with a longer time period (4 month) with in-season athletes. The researchers administered a series of ImPACT tests to 47 non-concussed Division III football players at preseason (before the first full-pads practice), midseason (6 weeks into the season), and postseason (within 2 weeks of the last game). The results indicated no significant differences in verbal memory ($p=.06$) and in processing speed ($p=.05$) over the 3 testing occasions. However, the scores for visual memory and reaction time showed significant improvement as the season progressed ($p=.04$ for both composite score). Even though the statistical difference was found at the P level of .05, when an 80% confidence interval was used, the ImPACT results could be interpreted as stable over a 4 month time period in football players. The test-retest reliability of ImPACT has been examined with even longer time periods. Several researchers have suggested shorter re-administration of neurocognitive baseline (ie., every year) assessment for adolescent athletes due to their on-going cognitive development and maturation. In response, Elbin et al. (2011) investigated the 1-year test-retest reliability of the online version of ImPACT using the baseline data from 369 varsity high school athletes. The researchers administered the ImPACT approximately 1.2 years (range, 0.5-2.35 years) apart as required by the participants' respective athletic programs. Results showed that motor processing speed was the most stable composite score with ICC of .85, followed by reaction time (.76), visual memory (.70), verbal memory (.62), and PCSS (.57). Considering the fact that ICC of .60 and .70 have been recommended as minimum acceptable ICC (Baumgartner & Chung, 2001), this study suggested that ImPACT baseline data can be used reliably for 1 year in high school athletes. Low

ICC for PCSS (.57) was not unexpected because it has been found to show some variability at baseline (Covassin, Schatz, & Swanik, 2007; Swanik, Covassin, Stearne, & Schatz, 2007).

The test-retest study of ImPACT with the longest time period was conducted by Schatz et al. (2010), which examined two baseline data intervals, approximately 2 years apart. This study included 95 collegiate athletes. Results showed that motor processing speed is the most stable composite score over 2 years with ICC of .74, followed by reaction time (.68), visual memory (.65), verbal memory (.46), and then total symptom score (.43). Most of these findings are consistent with the study by Elbin and colleagues (2011). Even though the ICC for verbal memory did not reach the “acceptable” threshold (.60), with use of regression based methods, none of the participant’s scores showed significant change. Also, reliable change indices revealed that only a small percentage of participants showed significant change (0 to 3%). This study suggested that college athletes’ cognitive performance remains stable over a 2-year time period.

In contrast to these findings that support the test-retest reliability of ImPACT, Broglio et al. (2007) reported low ICC for all ImPACT composite scores. Using 118 healthy college students, the researchers examined test-retest reliability of ImPACT and two other neuropsychological tests (Concussion Sentinel and CRI) through three administrations: baseline, 45 days after the baseline, and 50 days after the baseline. For ImPACT, the researchers reported ICC ranging from .28 to .38 (baseline to day 45), and .39 to .61 (day 45 to day 50). The ICC for each composite score were as follows: verbal memory (.23 for baseline to day 45, and .40 for day 45 to day 50), visual memory (.32 and .39, respectfully), motor processing speed (.38 and .61, respectfully), and reaction time (.39 and .51, respectfully). As it has been mentioned previously, these low ICC values may have been attributable to methodological problems caused by

administering three different computerized neurocognitive assessments in succession (ImPACT, Headminder's CRI, and Concussion Sentinel).

While the acceptable test-retest reliability of ImPACT for short term (7days) and long term (1 and 2 years) have been reported (Iverson et al., 2003; Schatz et al., 2010; Elbin et al., 2011), no study has been conducted to re-examine the test-retest reliability of ImPACT for mid-term (45-50 days) after Broglio et al. (2007) reported low ICC. Re-examination of test-retest reliability of ImPACT for mid-term is warranted without the confounding factors that have been pointed out in the study of Broglio et al. (2007). In the next section, another possible confounding factor, which is the effect of physical activity on cognitive function will be reviewed.

Physical Activity and Neurocognitive Performance

The benefit from participating in physical activities is not limited to the reduction of risk for physical disorders such as cardiovascular disease, colon and breast cancer, and obesity. Studies have also found the positive effect of physical activity on cognitive function. In animals, it has been shown that exercise increases neurogenesis in a brain structure, which result in improving learning and memory (Praag, Christie, Sejnowski, & Gage, 1999; Vaynman & Gomez-Pinilla, 2006). In human research, the effects of physical activity on cognitive function have been studied with various age groups ranging from children to elderly.

A meta-analysis was conducted on 44 studies to determine the effect of physical activity on cognition in school-age children (aged 4-18 years). In this study physical activity included resistance/circuit training, perceptual-motor training, physical education program, and aerobic activity. Cognitive function included perceptual skills, intelligence quotient, achievement, verbal tests, mathematic tests, memory, developmental level, and academic readiness. The results

indicated a statistically significant positive relation between physical activity and all cognitive performance (Effect Size=.32, SD=.27) with the exception of memory (Sibley & Etnier, 2003).

The above mentioned meta-analysis study is consistent with a more recent meta-analysis study conducted by Fedewa and Ahn (2011) which reported effect size of .35 (95%CI:.27-.43) under mixed-effect model, and .32 (95% CI: .26-.37) from cross sectional/correlation data. In this study, a total of 59 studies were analyzed in order to quantitatively synthesize the research on physical activity and cognitive outcomes in children (aged 3-18 years). The physical activities were categorized into total physical fitness, development, strength, flexibility, and cardio. Cognitive outcome measures included intelligence quotient, total achievement, vocabulary/spelling/language/art achievement, reading achievement, mathematics achievement, science achievement, grade-point average, and other such as creativity. The results showed a significant and positive impact of physical activity on children's cognitive outcomes.

The study of physical activity and cognition in middle-age and older adults have been conducted mainly with the purpose of maintenance of cognitive function and reduction of the risk for age-associated cognitive disorders such as Alzheimer's disease and vascular dementia. Regular physical activity can be thought to be a neuroprotective therapy due to significant benefits of long-term, regular physical activity on cognition, dementia risk, and dementia progression (Ahlskog, Geda, Graff-Radford, & Petersen, 2011). A relatively recent meta-analysis of prospective cohort studies reported the protective effect of physical activity in midlife against the risk of neurocognitive diseases (Hamer & Chida, 2009). The results showed the relative risk of Alzheimer's disease and dementia in adults who routinely engaged in physical activity in their midlife compared with sedentary adults was .55 (95%CI: .36-.84) and .72 (95%CI: .6-.86), respectively.

Compared to the other age group, there is a dearth of research on the effect of physical activity on cognition in young adults (Hillman, Erickson, & Kramer, 2008). The study of Kamijo and Takeda (2009) is one of the few studies that have examined the relationship between physical activity level and the cognitive function of executive control in young adults. In this study, the physical activity level of 40 young adults (mean age=21.1) were evaluated using the International Physical Activity Questionnaire (IPAQ) long form, which assesses leisure time physical activity, domestic and gardening activities, work-related physical activity, and transport-related physical activity. Based on the IPAQ, participants were categorized in a physically active group (n=20, 9229.3kcal/week) and sedentary group (n=20, 1698.2kcal/week). The participants' electroencephalogram were measured during a spatial priming task, which asked the participants to respond to the location change of O while ignoring X (distracter) on the computer screen. This priming paradigm has been used to investigate facilitatory effects for target (positive priming, location of O does not change while location of X changes,), inhibitory effect (negative priming, location of O changes while location of X does not change), and control (both location of O and X change). This priming effect on reaction time and P3 latency was assessed as indicators of cognitive function, specifically executive control. The results revealed a larger negative priming effect on reaction time and P3 latency in the active group compared with the sedentary group, while positive priming effects were only observed in the sedentary group. This study indicates that physical activity has a beneficial effect on the cognitive processes on executive control in young adults.

Hillman and colleagues (2006) also used event-related brain potentials to examine the effect of physical activity level on processing speed and the updating of memory representation during the performance of switch and non-switch trials. In this study, the young adults who

participated in aerobic exercise more than five hours per week were categorized in physically active group (n=18, mean age=19.4), and those who participated in aerobic exercise less than 1 hour per week were categorized in sedentary group (n=16, mean age=19.4). Participants switched back and forth between two different tasks: determining whether the digit presented in the computer screen was greater or less than five; determining whether the digit presented was odd or even. Electroencephalogram was measured during the task. There were faster P3 latencies and greater amplitude of P3 component in the physically active group compared with sedentary group, which suggests regular physical activity improved executive control such as working memory, interference control, task coordination, and inhibitory control.

Since the effect of physical activity on cognitive function have been reported not only for older adult populations (Kramer, Erickson, & Colcombe, 2006) but also for young adults (Hillman, Kramer, Belopolsky, & Smith, 2006; Kamijo & Takeda, 2009), a test-retest reliability study must be conducted with physically active individuals in order to eliminate any effect of physical inactivity on cognitive function in the test-retest reliability study for ImPACT. Moreover, using physically active individuals will be more representative of athletes who are the primary users of the ImPACT neuropsychological test battery. Physical activity level of the participants were not taken into account in the study of Broglio et al. (2007), whereas the participants of other test-retest reliability were athletes (Iverson et al., 2003; Schatz et al., 2010; Elbin et al., 2011). In addition to the previously mentioned methodological problem, administering three neuropsychological testing successively in a testing occasion, and uncontrolled physical activity level of the participants may have affected the result of the study of Broglio et al. (2007). This leads to the purpose of the present study, which is to re-examine the

mid-term test-retest reliability of ImPACT by replicating the study of Broglio et al. (2007) while controlling for the previously mentioned confounding factors.

CHAPTER III

METHODOLOGY

Research Design

A repeated-measures design will be used to evaluate the test-retest reliability of the ImPACT neuropsychological test battery. The independent variable will be test group (baseline, 45 days after the baseline evaluation, and 50 days after the baseline evaluation). The dependent variables will be the composite scores of ImPACT including verbal memory, visual memory, motor processing speed, and reaction time. In addition, the Rey's 15-item memory test will be used before administration of ImPACT to determine effort from test-takers. Thus, dependent variables will also include the number of items that test-takers reproduced in Rey's 15-item memory test.

Participants

The participants selected for this study will be 120 college students who meet the inclusionary criteria that satisfy the following categories of basic recommendation for physically activity based on the American College of Sports Medicine (Garber et al., 2011).

Inclusionary criteria

The participants must meet the following basic recommendation: 1) Cardiorespiratory exercise—at least 150 minutes of moderate intensity exercise (4.8-7.1METs and PRE 12-13) or 75 minutes of vigorous intensity exercise (7.2-10.1 MET and PRE 14-17) per week. One continuous session and multiple shorter sessions of at least 10 minutes per session are both acceptable to accumulate the desired amount of exercise. Participants should meet the following two recommendations: 2) Resistance Exercise—two to four sets of 8-12 repetitions on major muscle group such as chest, shoulders, back, hips, legs, trunk, and arms two or three days week

using a variety of exercises and equipment. 3) Neuromotor exercise—two or three days per week of exercises that involves motor skills (balance, agility, coordination and gait). Multifaceted physical activities such as tai chi and yoga involve variety combinations of neuromotor exercise, resistance exercise, and flexibility exercise. The ACSM recommends 20-30 minutes per day to be sufficient for neuromotor exercise.

Exclusionary criteria

Participants will be excluded from the study if they have the following: 1) diagnosed with a learning disability, color blindness, attention deficit disorder, psychological disorder, brain surgery, or a major neurological condition (demyelinating disease, acute disseminated encephalomyelitis), 2) diagnosed with a concussion within 6 months before or during the study, 3) any athlete with a severe history of intracranial pathology (e.g., subdural hematoma) as determined by a positive CT or MRI, or 4) English was not their primary language.

Instrumentation

Immediate Post Concussion Assessment Cognitive Testing (ImPACT)

The computerized neurocognitive assessment program used will be the online version of ImPACT (ImPACT Applications, Inc., Pittsburgh, PA). The ImPACT program consists of three main sections including 1) demographic section, 2) postconcussion symptom scale (PCSS) section, and 3) neurocognitive test modules. In the demographic section, participants will be asked to input demographic and descriptive information such as years of experience playing sport, history of alcohol and drug use, learning disabilities, attention deficit hyperactive disorder, major neurological disorder, and previous concussion history. In the PCSS section, participants will be asked to self-report a total of 22 concussion related symptoms based on how they are feeling at the moment using a 7-point Likert scale (0=not experiencing this symptom, and

6=severely experiencing this symptom). The third category consists of six neurocognitive modules that are described below. Participants will be instructed to complete the given tasks as quickly and accurately as possible with their best effort.

ImPACT module one (Word discrimination). Attention processes and verbal recognition memory will be evaluated in the first module. Participants will be asked to memorize a list of 12 words (target words) that stay on the screen for 750 ms each. Each word shows up twice. Then a list of 24 words that comprised of 12 target words and 12 non-target words will be presented and participants will be asked if those words were in the original 12 words by answering “yes” or “no”. This task is for immediate recall memory. For delayed recall testing, another list of 24 words that are comprised of 12 target words and 12 non-target words will be presented and participants will be asked if those words were in the original 12 words by answering “yes” or “no”. Tests are scored based on a total percentage of correct answers.

ImPACT module two (Design memory). Visual recognition memory and attention processes will be evaluated in the second module measures. The testing process of this module is exactly the same as module one except that designs are used instead of words. Immediate recall memory and delayed recall memory will be evaluated by total percentage correct.

ImPACT module three(X’s and O’s). Visual working memory and visual processing speed will be evaluated by using a distractor task (choice reaction time) and memory task (visual memory). Athletes are presented a random screen of X’s and O’s with three yellow X’s and/or O’s. A distractor task is then presented. Participants will be asked to click the Q key on the keyboard if a blue circle is presented and click the P key on the keyboard if a red square is presented. After completing the distractor task, the same memory screen will show up and participants will be asked to click on the three previously illuminated yellow X’s and/or O’s.

This process will be repeated four times. The correct identification of the X's and O's will be scored as visual memory, and reaction time for the distractor task will be scored as reaction time.

ImPACT module four (Symbol matching). Nine common symbols (triangle, square, arrow, etc) matched with nine numbers (1-9) will be presented on a screen. Below these pairings, a symbol is randomly presented and participants will be asked to click on the matching number as quickly as they could while at the same time remembering the symbol/number pairings. The number will light up in different colors (green=correct number, red=incorrect number) to reinforce correct performance. Following the completion of 27 trials, the symbols will disappear from the top grid, and then randomly reappear below the grid. Participant will be asked to click on the number that matches the symbol. This module provides an average reaction time score and score for the memory recall.

ImPACT module five (Color match). Choice reaction time, impulse control and response inhibition will be measured in this module. First, participants will be asked to respond by clicking a red, blue, or green button on the screen as the words (RED, GREEN, and BLUE) are presented. The purpose of this test is to assure that the following tasks would not be affected by color blindness. Following the first task, a word will be displayed on the screen in the same or different colored ink (RED in red, or RED in green, etc). Participants will be asked to click on the mouse as quickly as they could only when the word is presented in the matching ink. A reaction time score and a score for the number of errors will be obtained from this module.

ImPACT module six (The letter memory). Visual motor response speed and working memory will be measured in this module. Three random letters will be presented on the screen and participants will be asked to remember the letters. Then participants will complete a distractor task, which is clicking the numbered button in a randomized 5 X 5 grid in backwards

order starting with 25 to 1. The numbered grid will disappear after 18 seconds, and then participants will be asked to type in the three letters that appeared on the screen before the distractor task. This procedure will be repeated five times. This module generates a memory score (total number of correctly identified letters) and a score for the average number of correctly clicked number in 18 seconds per trial from the distractor test. The entire ImPACT neuropsychological test takes approximately 20-25 minutes.

Rey's 15-Item Memory Test

Before administration of the ImPACT program, the Rey's 15-item memory test will be administered in order to evaluate test takers' effort. The test consists of 15 symbols on a piece of paper in five rows of three categorically related symbols. The symbols are easily identified letters, numbers, or figures (see Appendix A). Patients are exposed to the symbols for 30 seconds, and then asked to reproduce them without worrying about their order for two minutes. Test-takers who reproduced fewer than nine items will be considered malingering (Goldberg & Miller, 1986; Bernard & Fowler, 1990), which indicates lack of effort in this present study.

Physical Activity Level Survey

Participants will complete a survey regarding their physical activity level in order to assure the participants would be physically active throughout the study period. The intensity, duration, and frequency of cardiorespiratory exercise, resistance exercise, and neuromotor exercise will be assessed using this survey (see Appendix B).

Physical/Mental Condition Survey

Along with the physical activity survey, in order to control variables that may affect participants' performance on ImPACT, information such as physical fatigue level, stress level, food consumption, and caffeine intake of the testing day will also be gathered (see Appendix A).

Post-Testing Survey

Participants will also complete a short post-survey consisting of four questions. The first question will ask if the participant was distracted during the ImPACT and Rey's 15-item memory test. The second question will ask the participant if they had any technical difficulties (ie., slow mouse/computer). Finally the participants will be asked if the instructions were clear on the ImPACT and Rey's 15-item memory test tests (see Appendix C).

Procedures

This study will receive approval from the Institutional Review Board of Michigan State University prior to recruiting participants. Prior to participation, all participants will be required to sign the appropriate IRB approved consent forms. All participants will report to the same reserved computer laboratory for a total of three visits. There will be an approximately 45 days between the first and second session, and an approximately 50 days between the first and third session. Each session will last for approximately 40-45 minutes. All participants will complete Rey's 15-item memory test, demographic and physical activity survey, and the ImPACT neuropsychological test battery, which will be administered on a desktop computer with an optical mouse.

Data Analysis

Descriptive statistics will be performed for all tests to determine means and standard deviations. SPSS Version 16.0 (SPSS Inc., Chicago, IL) will be used to obtain ICC for each composite score. Specifically, a 2-way random effects analysis of variance ICC for absolute agreement will be calculated in order to estimate the test-retest reliability of ImPACT for baseline to day 45 assessments and for day 45 to day 50 assessments. ICC will range from 0 to 1, with an ICC closer to 1.00 indicating a stronger reliability. There are a variety of

recommendations for ICC interpretation. Baumgartner and Chung (2001) suggest an ICC of .60 to be minimally acceptable. Therefore, in the present study, an ICC of .60 will be used as the minimum acceptable ICC value. Test-takers who reproduced fewer than nine items will be considered malingering (Goldberg & Miller, 1986; Bernard & Fowler, 1990), which indicates lack of effort in this present study. Statistical significance will be set a priori at $p=.05$.

Evaluation of Hypotheses

- H1. There will be acceptable test-retest reliability ($ICC \geq .60$) in verbal memory composite scores over three test administrations (baseline, 45 days, 50 days) among physically active individuals.
- H2. There will be acceptable test-retest reliability ($ICC \geq .60$) in visual memory composite scores over three test administrations (baseline, 45 days, 50 days) among physically active individuals.
- H3. There will be acceptable test-retest reliability ($ICC \geq .60$) in motor processing speed scores over three test administrations (baseline, 45 days, 50 days) among physically active individuals.
- H4. There will be acceptable test-retest reliability ($ICC \geq .60$) in reaction time composite scores over three test administrations (baseline, 45 days, 50 days) among physically active individuals.
- H5. There will be no difference in test takers' effort level as measured by the Rey's 15-Item memory test over three test administrations (baseline, 45 days, 50 days).

CHAPTER IV

RESULTS

Overview

This research was conducted to investigate the test-retest reliability of the ImPACT neurocognitive test battery between baseline, 45 days and 50 days after baseline on physically active college students. The following chapter will describe the demographics of the sample and the ICC for the ImPACT test battery.

Demographic Data

There were a total of 127 subjects who participated in this study; however, data from 39 participants were excluded from further analysis for various reasons including missing one of the two post-baseline tests ($n=31$), invalid baseline ($n=1$), a value greater than 30 on Impulse Control scores ($n=2$), not maintaining the required physical activity level ($n=2$), and technical problem during testing ($n=3$). Therefore, there were a total of 88 participants (54 male, 34 female). The majority of participants were Caucasian (75%), followed by African American (6%), Hispanic or Latino (3%), Asian American (2%), and 2% of participants reported their ethnicity as “other.” History of concussion(s) was (were) reported from 21 participants with an average of 1.76 previous concussions ($SD = \pm 1.04$) that ranged from 1 to 4 previous injuries; however, no participants sustained a concussion during the testing period or in the 6 months prior to participating in this study. A summary of demographic data for age, height, and weight can be found in Table 4.1.

Table 4.1. Demographic Information for Age, Height and Weight

Group	Age (yrs)		Height (cm)		Weight (kg)	
	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>
Males (n=54)	20.05	± 1.96	179.96	± 7.59	78.56	± 11.33
Females (n=34)	19.77	± 1.02	164.72	± 7.69	63.66	± 9.38
Total (n=88)	19.95	± 1.66	174.07	± 10.65	72.80	± 12.83

Testing Intervals

The testing intervals between the baseline test and the second test was 44.2 ± 0.4 days, and the baseline test and the third test was 49.81 ± 0.40 days. Also, each participant except for three reported for each test session at the same time of day. In addition, location and the computer used were consistent throughout the test period.

Evaluation of the Hypotheses

The following behavioral results (H1 through H5) are combined into the categories of the computerized neurocognitive test results and the Rey's 15-item memory test results.

Results of Computerized Neurocognitive Testing (Hypotheses 1 – 4):

There will be acceptable test-retest reliability ($ICC \geq .60$) in computerized neurocognitive test performance (ImPACT Composite Scores: verbal and visual memory, motor processing speed, reaction time) over three test administrations (baseline, 45 days, 50 days) among physically active individuals.

Hypotheses 1 through 4 were supported as the ICC values on the all ImPACT composite score were equal or higher than .60, which indicates acceptable test-retest reliability. Among the composite scores, motor processing speed reported the highest overall ICC value with .90, and visual memory reported the lowest overall ICC value with .75. Specifically, the highest ICC

value (.87) was reported from motor processing speed between day 45 and day 50, and the lowest ICC value (.60) was reported from visual memory between baseline and day 50. With exception of verbal memory, the ICC values from day 45 to day 50 were higher than the ICC values from baseline to day 45, and from baseline to day 50. The means, standard deviations, and range for each ImPACT composite score can be found in Table 4.2, and the mean differences of each ImPACT composite score between testing days can be found in Table 4.3 (see Figures 4.1-4.4). The ICC values for each ImPACT composite score from baseline to day 45, day 45 to day 50, and baseline to day 50 can be found in Table 4.4. The Cronbach's alpha values were also calculated for each ImPACT composite score from baseline to day 45, day 45 to day 50, and baseline to day 50, and the summary can be found in Table 4.5.

Table 4.2. Means and Standard Deviations for ImPACT Composite Scores at Baseline, 45 days after the Baseline, and 50 days after the Baseline

	Baseline		45 days		50 days	
	<i>Mean± SD</i>	<i>Range</i>	<i>Mean± SD</i>	<i>Range</i>	<i>Mean± SD</i>	<i>Range</i>
Verbal Memory	85.75±10.31	65-100	88.33±10.07	55-100	89.43±8.53	66-100
Visual Memory	76.07±12.23	41-99	77.95±13.25	49-99	73.20±12.62	46-99
Motor Processing Speed	41.16±6.02	28.58-53.15	42.57±6.13	29.28-52.33	43.01±5.91	29.38-52.58
Reaction Time	0.59±0.09	0.97-0.44	0.58±0.08	0.98-0.46	0.58±0.07	0.75-0.47
Impulse Control	5.15±3.49	0-17	5.57±3.81	0-20	5.65±4.1	0-29

Table 4.3. Pair-wise Comparison of ImPACT Composite Scores at Baseline, 45 days after the Baseline, and 50 days after the Baseline

	Mean Difference (<i>p</i> -value)		
	Baseline vs Day 45	Day 45 and Day 50	Baseline vs Day 50
Verbal Memory	2.60 (.006)*	1.10 (.256)	3.71 (.000)*
Visual Memory	1.89 (.135)	-4.75 (.001)*	-2.86 (.047)*
Motor Process Speed	1.41 (.001)*	.439 (.307)	1.85 (.000)*
Reaction Time	.011 (.248)	-.007 (.261)	.003 (.695)
Impulse Control	-.420 (.236)	-.080 (.819)	-.500 (.262)

* $p \leq .05$

Figure 4.1. Composite Score for ImPACT Verbal Memory at Baseline, 45 days after the Baseline, and 50 days after the Baseline. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.

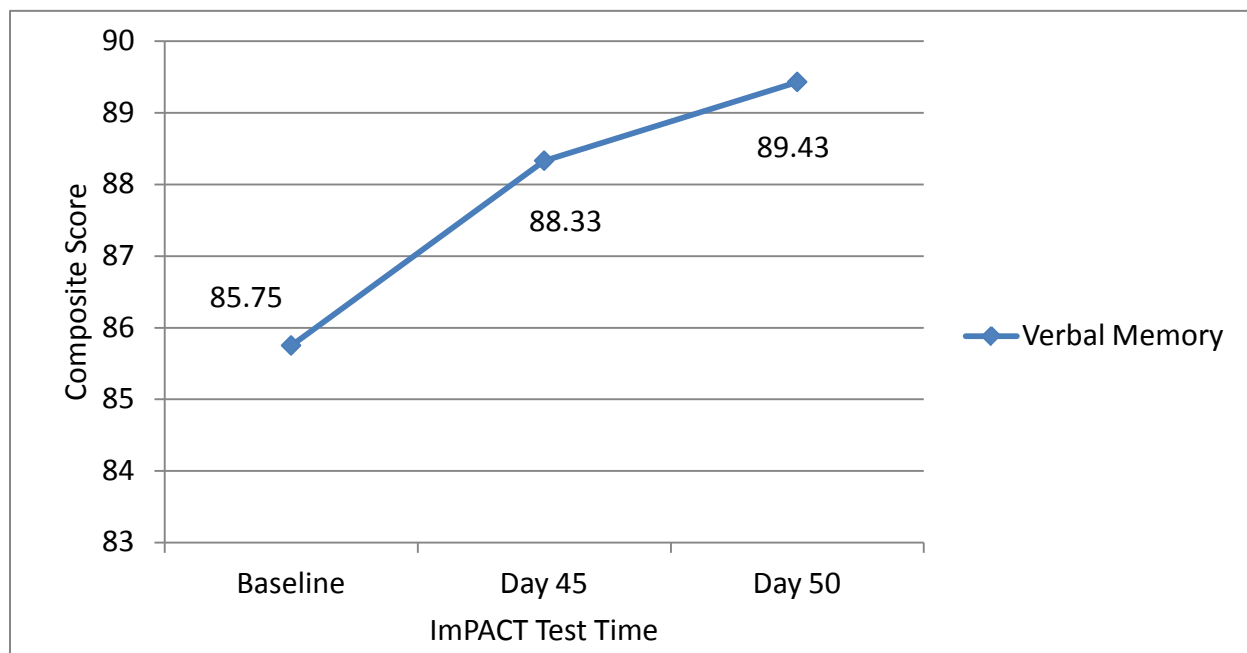


Figure 4.2. Composite Score for ImPACT Visual Memory at Baseline, 45 days after the Baseline, and 50 days after the Baseline

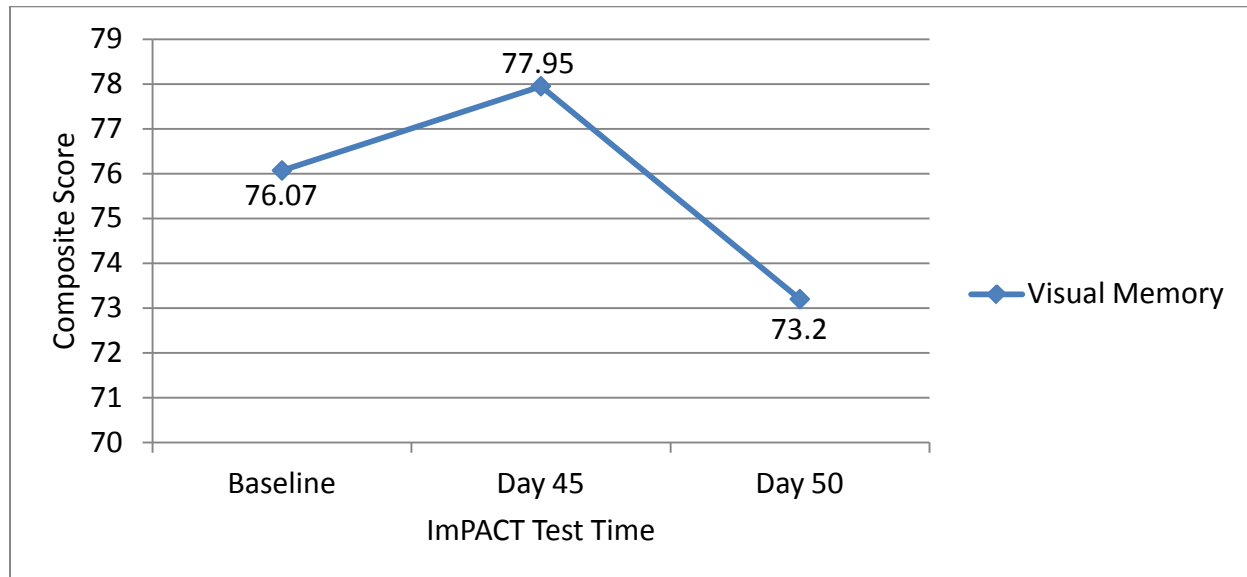


Figure 4.3. Composite Score for ImPACT Motor Processing Speed at Baseline, 45 days after the Baseline, and 50 days after the Baseline

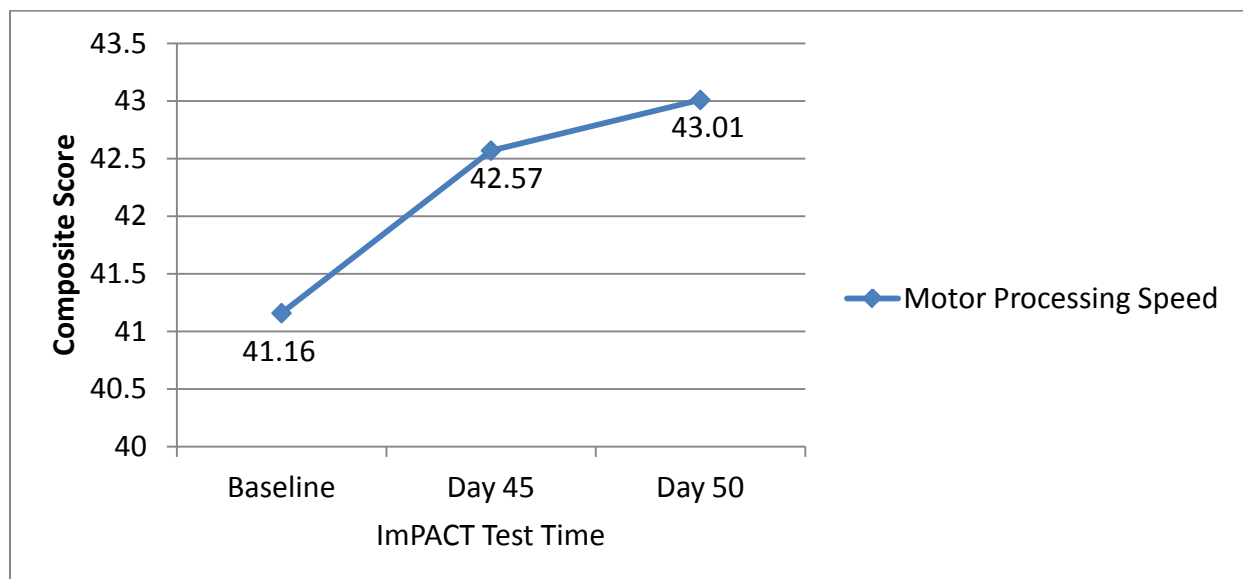


Figure 4.4. Composite Score for ImPACT Reaction Time at Baseline, 45 days after the Baseline, and 50 days after the Baseline

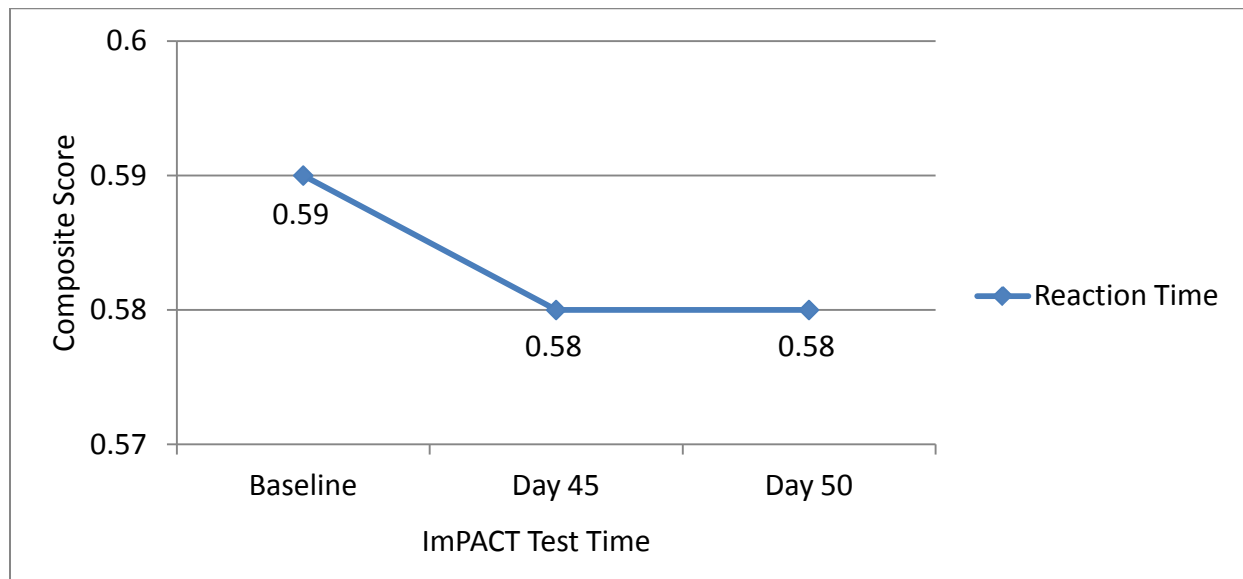


Table 4.4. Intraclass Correlation Coefficients for ImPACT Composite Scores between Baseline and Day 45, Day 45 and Day 50, Baseline and Day 50, and Overall

	Verbal Memory	Visual Memory	Motor Processing Speed	Reaction Time	Impulse Control
Baseline to Day 45	.76	.72	.86	.68	.74
Day 45 to Day 50	.69	.66	.87	.83	.80
Baseline to Day 50	.66	.60	.84	.72	.57
Overall	.78	.75	.90	.81	.79

Table 4.5. Cronbach's Alpha for ImPACT Composite Scores between Baseline and Day 45, Day 45 and Day 50, Baseline and Day 50, and Overall

	Verbal Memory	Visual Memory	Motor Processing Speed	Reaction Time	Impulse Control
Baseline to Day 45	.77	.73	.87	.69	.74
Day 45 to Day 50	.69	.68	.87	.83	.80
Baseline to Day 50	.69	.59	.86	.73	.57
Overall	.80	.76	.91	.81	.79

Results of the Rey's 15-item memory test (Hypothesis 5):

There will be no difference in test takers' effort level as measured by the Rey's 15-item memory test over three test administrations (baseline, 45 days, 50 days).

Hypotheses 5 was supported as the moderate ICC values for test takers' effort level and almost no variance in the Rey's 15-item memory test were reported. Effort level was calculated using the Rey's 15-memory test and asking the participant to rate their effort level on a scale of 0-10. The ICC values for test takers' self-rated effort level were .84, .83, .78, and .74 for overall, baseline and day 45, day 45 and day 50, and baseline and day 50, respectively. Cronbach's Alpha values were exactly the same as the ICC values. As for the Rey's 15-item memory test, all participants scored full score (15points) throughout the testing period with an exception of one participant who scored 12 points at the second test. Due to its little variance, it was unable to calculate ICC value for the Rey's 15-item memory test. The means, standard deviations, and range for Rey's 15-item memory test and self-reported effort level can be found in Table 4.6.

Table 4.6. Means and Standard Deviations for Rey's 15-item Memory Test, and Self-Reported Effort Level

	Baseline		45 days		50 days	
	<i>Mean± SD</i>	<i>Range</i>	<i>Mean± SD</i>	<i>Range</i>	<i>Mean± SD</i>	<i>Range</i>
Rey's 15 Memory Test	15±0.00	15-15	14.97±0.32	12-15	15±0.00	15-15
Self Reported Effort Level	9.56±0.87	3-10	9.53±.87	7-10	9.27±1.20	4-10

Evaluation of Survey Data and Total Symptom Score

Along with ImPACT and Rey's 15-item memory test, additional data was collected from the participants in order to evaluate the participants' physical and mental condition as well as the quality of the testing environment.

Physical Activity Level

Participants were assessed their physical activity level throughout the study period based on the amount of physical activity including moderate cardio exercise (4.8-7.1METs and PRE 12-13), vigorous cardio exercise (7.2-10.1 MET and PRE 14-17), resistance exercise (two to four sets of 8-12 repetitions on major muscle group), and neuromotor exercise (balance, agility, coordination and gait). Participants who did not meet the set criteria were excluded from further analysis (n=2). The means and standard deviations for the amount of the exercise at baseline, 45 days after the baseline, and 50 days after the baseline (minutes/week) can be found in Table 4.7.

Table 4.7. Means and Standard Deviations for the amount of the exercise at Baseline, 45 days after the Baseline, and 50 days after the Baseline (minutes/week)

	Baseline	45 days	50 days
Type of the Exercise	<i>Mean± SD</i>	<i>Mean± SD</i>	<i>Mean± SD</i>
Moderate Cardio	133.75±136.72	112.13±95.92	102.24±88.58
Vigorous Cardio	217.44±193.94	196.53±154.65	198.66±182.94
Resistance Training	175.63±120.95	163.41±112.05	177.82±144.51
Neuromotor Exercise	69.54±119.89	75.52±121.29	79.46±133.62

Condition of the Participants and Testing Environment

Along with the physical activity, in order to evaluate variables that may affect participants' performance on ImPACT, information such as physical fatigue level, stress level, food consumption, and caffeine intake of the testing day were gathered. Also, in order to evaluate the testing environment, distraction level and presence of technical problems during testing were assessed. The means, standard deviations, and range of those variables can be found in table 4.8 and figure 4.5. Pair-wise comparisons revealed significant differences for total symptom score between day 45 and day 50 (mean difference: 2.06) and between baseline and day 50 (mean difference: 1.97), physical fatigue level between baseline and day 45 (mean difference: -.80) and between day 45 and day 50 (mean difference: .50), distraction level between day 45 and day 50 (mean difference: -.57) and between baseline and day 50 (mean difference: -.45). The mean differences and *p* values can be found in table 4.9, and their statistical and clinical significance will be discussed in next chapter. The overall ICC values showed that the physical and mental condition of the participants were consistent throughout the testing period (.90, .85, .73, .80,

and .64 for ImPACT total symptom score, stress level, physical fatigue level, food consumption, and caffeine intake, respectively) with an exception of hours of sleep (.56). Also, low distraction level (1.58, 1.55, and 2.06 at baseline, day 45, and day 50, respectively) with acceptable consistency (overall ICC of .65) was reported. Total of three subjects reported technical problems including difficulty of pointing the mouse (n=1), slow response of mouse (n=1), freezing of the ImPACT program (n=1), subsequently they were excluded from further analysis.

Table 4.8. Summary of the Condition of the Participants and Testing Environment

	Baseline		45 days		50 days	
	<i>Mean± SD</i>	<i>Range</i>	<i>Mean± SD</i>	<i>Range</i>	<i>Mean± SD</i>	<i>Range</i>
Total Symptom	10.88±10.93	61-0	10.97±11.79	53-0	8.91±11.19	47-0
Hours of Sleep	6.99±1.53	0-10	7.23±1.92	3-15	6.78±1.62	0-9
Stress ^a	4.98±2.21	0-9	4.55±2.38	0-10	4.40±2.74	0-10
Physical Fatigue ^a	3.12±2.30	0-8	3.81±2.61	0-9	3.41±2.68	0-10
Food Intake ^b	7.0±2.8	0-10	6.8±3.5	0-10	6.5±3.5	0-10
Caffeine Intake ^c	4.2±1.8	0-8	4.4±1.7	0-10	3.8±1.9	0-9
Distraction ^a	1.58±1.70	0-8	1.55±1.97	0-9	2.06±2.21	0-8

^a rated on scale of 0-10, where 0 is not stressed/fatigued/distracted at all and 10 is very stressed/exhausted/distracted

^b rated on scale of 0-10, where 0 is not typical food intake at all and 10 is very typical food intake

^c rated on scale of 0-10, where 0 is much less than typical caffeine intake, 5 is typical caffeine intake, and 10 is much more than typical caffeine intake

Table 4.9. Pair-wise Comparison of the Condition of the Participants and Testing Environment at Baseline, 45 days after the Baseline, and 50 days after the Baseline

	Mean Difference (<i>p</i> -value)		
	Baseline vs Day 45	Day 45 vs Day 50	Baseline vs Day 50
Total Symptom	-.09 (.918)	2.06 (.006)*	1.97 (.030)
Hours of Sleep	-.24 (.455)	.46 (.455)	.22 (.455)
Stress ^a	.357 (.115)	.214 (.254)	.571 (.023)*
Physical Fatigue ^a	-.80 (.008)*	.500 (.077)	-.298 (.276)
Food Intake ^b	.244 (.486)	.280 (.382)	.524 (.143)
Caffeine Intake ^c	-.143 (.549)	.548 (.011)*	.405 (.084)
Distraction ^a	.119 (.639)	-.571 (.023)*	-.452(.044)*

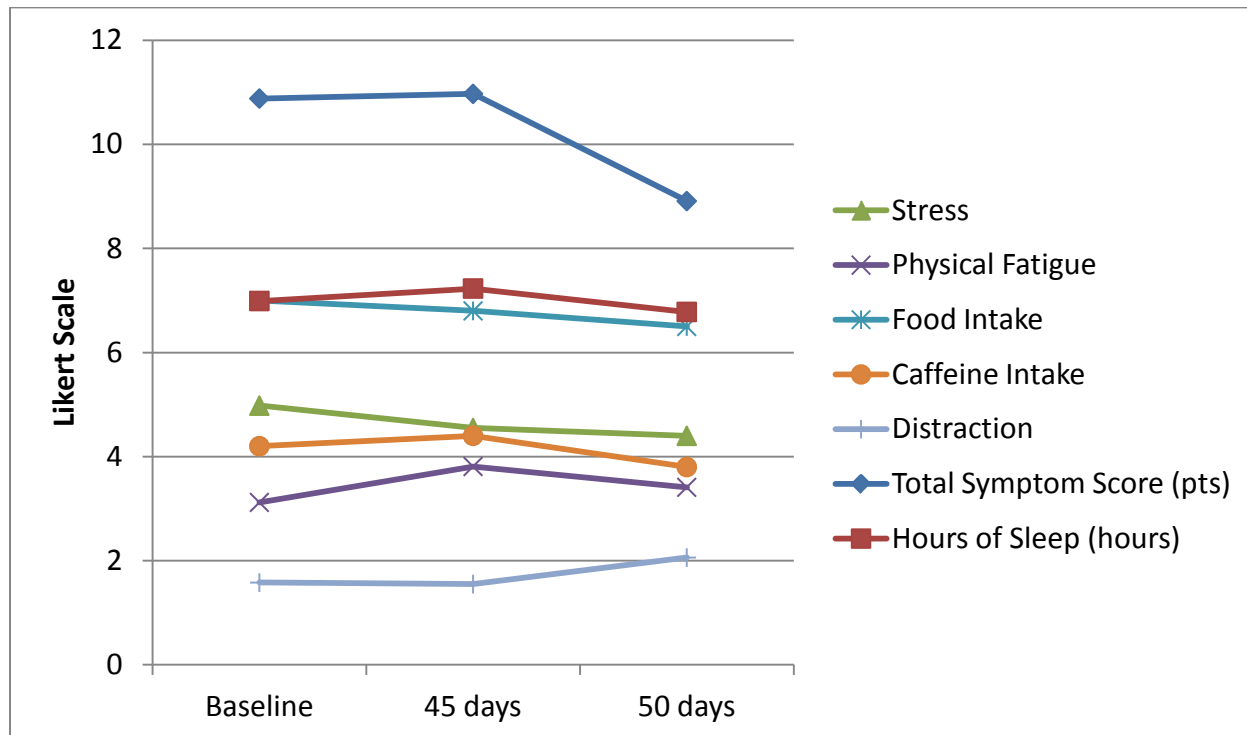
^a rated on scale of 0-10, where 0 is not stressed/fatigued/distracted at all and 10 is very stressed/exhausted/distracted

^b rated on scale of 0-10, where 0 is not typical food intake at all and 10 is very typical food intake

^c rated on scale of 0-10, where 0 is much less than typical caffeine intake, 5 is typical caffeine intake, and 10 is much more than typical caffeine intake

*The mean difference is significant at the .05 level

Figure 4.5. Condition of the Participants and Testing Environment at Baseline, 45 days after the Baseline, and 50 days after the Baseline



Evaluation of Association between ImPACT Composite Scores and Survey Data and Total Symptom Score

Pair-wise comparison revealed mean differences with statistical significance in some of the ImPACT composite scores, survey data, and total symptom score between testing days. Linear multiple regressions analysis with score difference in ImPACT composite scores between testing days as the dependent variables and corresponding score difference in survey data and total symptom score that showed statistical significant mean difference in the previous analysis as the independent variables was conducted in order to assess if any of the statistically significant changes in survey data and total symptom score explain the score changes in ImPACT composite scores. The analysis revealed a significant relationship between the change of visual memory composite score and the change of distraction level ($R^2=.066$, $B=-1.40$, $t=-2.46$, and $p=.016$)

with correlation of $-.256$ ($p=.008$) between 45 and 50 days after the baseline, and between the change in verbal memory composite score and the change of total symptoms score ($R^2=.050$, $B=.247$, $t=2.125$, and $p=.036$) with correlation of $.223$ ($p=.018$) between baseline and 50 days after the baseline.

CHAPTER V

DISCUSSION

Introduction

The primary purpose of the current study was to re-examine the test-retest reliability of the ImPACT neurocognitive test battery between baseline, 45 days and 50 days after baseline on physically active college students while assessing the participants' physical and mental condition on the testing day. The ICC values on each composite score from the current study met or exceeded the .60 level, which is the indication of acceptable test-retest reliability (Baumgartner & Chung, 2001), and were higher than the ICC values obtained by Broglio et al. (2007). In chapter 5, this primary result will be discussed in relation to the relevant literature on test-retest reliability of the ImPACT neurocognitive test battery. While acceptable test-retest reliability was obtained, performance fluctuation was observed through the testing period in the absence of concussion. In order to explore the performance fluctuation, the survey results will be reviewed and discussed in relation to the relevant literature on the effects of the physical and mental condition on neurocognitive function. Finally, clinical implications of these findings and suggestions for future research will be proposed.

Comparison of ICC Values with Other Studies

Comparison with the Study of Broglio et al. (2007)

ICC values from the current study were higher than the ICC values obtained by Broglio et al. (2007) for all of the composite scores measured. The ICC ranged from .60 to .87 for the current study, while .15 to .61 for the study by Broglio et al. While all ICC values in the study of Broglio et al. were greater between day 45 and day 50 than between baseline and day 45 (ICC values between baseline and day 50 was not available), the same trend was not observed in the

current study, which suggests that a shorter testing interval (45 days vs 50 days) does not necessarily result in higher ICC values in ImPACT composite scores. The comparison of ICC values between two studies can be found in Table 5.1.

Table 5.1. Comparison of ICC Values between the Current Study and Broglio et al. (2007)

	Verbal Memory	Visual Memory	Motor Processing Speed	Reaction Time	Impulse Control
<i>Baseline to Day 45</i>					
Current Study	.76	.72	.86	.68	.74
Broglio et al. (2007)	.23	.32	.38	.39	.15
<i>Day 45 to Day 50</i>					
Current Study	.69	.66	.87	.83	.80
Broglio et al. (2007)	.40	.39	.61	.51	.54
<i>Baseline to Day 50</i>					
Current Study	.66	.60	.84	.72	.57
Broglio et al. (2007)	N/A	N/A	N/A	N/A	N/A
<i>Overall</i>					
Current Study	.78	.75	.90	.81	.79
Broglio et al. (2007)	N/A	N/A	N/A	N/A	N/A

There are several factors that may contribute to the differences between Broglio et al. (2007) and the current study. First, there is a notable difference in the primary reason of data exclusion between the two studies. While invalid ImPACT baseline assessment accounted for 64% of the data exclusion (29 of 45 exclusions) in the study of Broglio et al., invalid baseline (i.e., flagged by ImPACT as invalid) assessment accounted for less than 3% (1/39) of the data exclusion in the current study. When a value greater than 30 on Impulse Control is included as a reason for data exclusion (n=2), test takers' performance related reasons (an invalid baseline and

a value greater than 30 on Impulse Control) accounted for less than 8% (3/39) of data exclusion in the current study, which is still considerably low compared with the study of Broglio et al. It was not clear whether a value greater than 30 on Impulse Control scores were included as an indicator of invalid assessment in the study of Broglio et al. Rather, in the current study, missing appointments was the major reason for data exclusion, which accounted for 79% (31 of 39 exclusions) of all excluded subjects.

Schatz and colleagues (2012) examined the prevalence of invalid baseline based on the ImPACT Version 2.0 Clinical Users' Manual, and reported that 4.1% of 1388 collegiate athletes had at least one of the indicators for invalid assessment including a value greater than 30 on Impulse Control scores. Also, other test-retest reliability studies with different testing intervals reported comparably low rate of invalid ImPACT baseline assessment including 5.9% rate of invalid baseline in 117 collegiate athletes in the study of Schatz et al. (2010) and 7.8% rate of invalid baseline in 484 high school athletes in the study of Elbin et al. (2011). While the current study reported 0.8% (1 of 127) of invalid baseline, it is obvious that 26% rate of invalid baseline in the study of Broglio et al. (2007) is notably high when it is compared to not only the current study, but also other studies.

Second, the high number of invalid baseline data in the study of Broglio et al. (2007) calls into a question the quality of test taker's performance on ImPACT including their level of effort. It is reasonable to assume that their participants were not able to provide their best performance due to fatigue and stress caused by three consecutive administrations of neurocognitive tests. One may argue that invalid data were excluded from analysis so that the analyzed data was reliable. Erdal (2012) suggested that ImPACT test takers can report significantly lower scores than their baseline assessments without detection by validity indicators,

which indicates that having valid data at two testing points does not necessarily mean their performance are the same.

Third, even though Broglio et al. (2007) stated that the participants exhibited good effort on all days of testing based on the results from Memory and Concentration Test for Windows (MACT), there is no evidence that MACT can accurately assess the effort that is required to complete ImPACT. In fact, in the current study, test takers' effort was assessed by the Rey's 15-item memory test that is used for detecting malingering (Goldberg & Miller, 1986; Bernard & Fowler, 1990) and all three participants who reported invalid ImPACT assessment had a perfect score on the Rey's 15-item memory test. Thus, this indicates that the Rey's 15-item memory test was not sensitive to assess the effort that is required for ImPACT.

Finally, the administration of the three neuropsychological tests and the MACT was not clearly stated in the study of Broglio et al. (2007). If the authors randomized the order of the three test administrations at every testing occasion, it could have affected the ICC values. If ImPACT was administered as the first test of three at baseline and as the last test of three at the day 45, it is not hard to expect a better performance at baseline than day 45. At the same time, if the authors did not randomized the order of testing administration, the reported ICC values on ImPACT composite scores were reliable only if ImPACT was the first neurocognitive test administered so that it was not affected by the previously administered neurocognitive test. Moreover, unclear timing of MACT administration calls into a question the reliability of effort assessment in their study. As a result, Broglio's et al. research design of administering three different neurocognitive tests consecutively contributed to the low reliability/ICC of ImPACT.

Comparison with Elbin et al. (2011) and Schatz et al. (2010)

While Miller et al. (2007) used 80% confidence interval instead of ICC, Elbin et al. (2011) and Schatz et al. (2010) reported ICC values of ImPACT composite scores with 1-year and 2-year testing interval. ICC values reported by Elbin et al. exceeded the cut-off value of 0.60 for all composite scores, and the same result was reported in the study of Schatz et al. with an exception of Visual Memory (ICC=.46). With a few exceptions, the ICC values obtained in the current study were generally greater than these two studies, and several factors could explain the differences. First, the current study used a shorter testing interval compared to the study of Elbin et al. and Schatz et al. This shorter test period could have resulted in high ICC. Second, Elbin et al. used high school athletes with a mean age of 14.8 years compared to the current study which used collegiate students. The adolescent brain is still developing which could have affected the ICC values. Third, data in the current study was obtained from a volunteered non-athlete population while both the other two studies used volunteered athletes. Thus, physical fitness of the participants could have attributed to the differences in ICC values.

Test-Retest Reliability Difference across the Composite Scores

The majority of research studies examining ICC of the ImPACT test, including this study, suggest that some ImPACT composite scores have higher test-retest reliability than other composite scores. The highest ICC value was always found in Motor Processing Speed with an exception of the study by Broglio et al. (2007) between baseline to day 45. In contrast, the lowest ICC was always reported from either Verbal Memory or Visual Memory when Impulse Control is excluded. It is important for clinicians to acknowledge that the test-retest reliability systemically varies across ImPACT composite scores. The summary of the ICC values across the studies can be found in Table 5.2.

Table 5.2. Comparison of ICC Values across the Test-Retest Studies

Study & Testing Interval	Verbal Memory	Visual Memory	Motor Processing Speed	Reaction Time	Impulse Control
<i>Miller et al. (2007)</i>					
Baseline to 120 days	No statistical difference with 80% confidence interval				N/A
<i>Elbin et al. (2011)</i>					
Baseline to 1 year	.62 ^b	.70	.85 ^a	.76	N/A
<i>Schatz et al. (2010)</i>					
Baseline to 2 year	.46 ^b	.65	.74 ^a	.68	N/A
<i>Broglia et al. (2007)</i>					
Baseline to Day 45	.23 ^b	.32	.38	.39 ^a	.15
Day 45 to Day 50	.40	.39 ^b	.61 ^a	.51	.54
<i>The current study</i>					
Baseline to day 45	.76	.72 ^b	.86 ^a	.68	.74
Baseline to day 50	.69	.66 ^b	.87 ^a	.80	.80
Day 45 to day 50	.66	.60 ^b	.84 ^a	.72	.57
Overall	.78	.60 ^b	.84 ^a	.81	.79
		.75 ^b	.90 ^a		

^a the highest ICC value among the composite scores obtained at a time

^b the lowest ICC value among the composite scores obtained at a time

Discussion of Survey Data

General Discussion

In order to simulate athletes, the current study was conducted with physically active individuals. Physical activity level of the participants at each testing sessions was assessed in order to confirm that the participants satisfied the ACSM guideline for physical activity recommendation. The majority of participants satisfied and kept their required physical activity level throughout the testing periods. Three participants reported no resistance training at some

testing sessions, but were still included in data analysis due to their high amount of vigorous intensity exercise (more than 150 minutes per week). Even though the average of moderate intensity exercise fell below the recommended 150 minutes per week (average of 116 minutes per week), the shortfall of moderate intensity exercise was compensated by high amounts of vigorous intensity exercise that averaged more than twofold greater than recommended 75 minutes per week (average of 204 minutes per week). The average amount of resistance training was 171 minutes per week, and a participant was assumed to satisfy the recommended amount of resistance training (two to four sets of 8-12 repetitions on major muscle group two or three days per week) if he or she reported more than 30 minutes of resistance training per week. While it was not an exclusionary criterion, the average amount of neuromotor exercise surpassed the recommended 20-30 minutes of two to three times per week with approximately 75 minutes per week.

Kamijo and Takeda (2008) reported a beneficial effect of physical activity on cognitive function in young adults. In their study, the energy consumption of the participants was measured by the International Physical Activity Questionnaire (IPAQ), and the participants in the active group averaged 6592.1kcal/week of estimated leisure time energy consumption whereas the participants in the sedentary group had an average of 582.4kcal/week in the same domain. However, the IPAQ takes into account daily walking thus elevating their energy consumption. In the current study, the average of participants' estimated energy consumption based on their body weight, duration of the physical activity, and intensity of the physical activity (5.9METS for moderate intensity exercise, resistance training, and neuromotor exercise, and 8.6METS for vigorous exercise) were 5176.3, 4754.6 and 4739.3 kcal/week at baseline, day 45, and day 50. Thus participants in the current study are thought to be physically active enough

to receive a benefit on their cognitive function. Therefore, the aim of using physically active participants in order to simulate athletes who are thought to benefit on their cognitive function due to their high physical activity level was accomplished.

Test performance can be influenced by the participants' physical and mental condition, as well as by the testing environment. The effect of exercise induced fatigue on cognitive function has been studied with different methods, intensity of exercise, cognitive tasks, and timing of cognitive task administration. A meta-regression analysis reported the complex relation between exercise and cognition (Lambourne & Tomporowski, 2010). Using ImPACT as the measurement instrument, Covassin et al. (2007) reported a limiting effect of maximal exercise on verbal memory composite score with statistical significance; therefore, vigorous exercise prior to the test was discouraged. Attempts were also made to minimize the effects of environment by testing a participant in the same reserved quiet computer lab at the same time of day for all test sessions with average of approximately five participants at a time. Based on the survey data rated on a scale of 0 to 10, as a general impression, the participants were moderately stressed (average ~5) and mildly fatigued (average ~3.5) , and series of ImPACT were administered under low level of distraction (average~1.5). The relationship between the data from survey/total symptoms score and ImPACT composite scores will be discussed in the next section.

Statistical vs Clinical Significance

Even though some differences in participants' physical and mental condition between testing days were statistically significant, they can be viewed as non clinically significant. The mean statistical difference for total symptom score was an average of 2.0 which is extremely low considering the range was between 0 and 132. The mean statistical difference for physical fatigue and distraction was on average 0.50 out of a scale from 0-10. Thus all mean differences

for physical fatigue level and distraction level were less than one, which is smaller than its rating increment, and the mean differences for total symptom score were also considerably small at approximately two. Therefore, despite their statistical significances, the participants' physical and mental condition can be considered clinically stable during the testing period along with the other physical, mental, and environmental conditions that had no statistical significant differences between testing days.

While the effect of fatigue induced by acute exercise has been studied, the effect of general physical fatigue on cognitive function has not been studied. In the current study, the mean of participants' physical fatigue level on average was 3.5 on a scale of 0 to 10. The multiple regressions revealed that there were no significant relationships between the changes in physical fatigue level and any of the changes in ImPACT composite scores, even when the difference of physical fatigue level was statistically significant between day 45 and 50. This result may be attributed to the small mean difference of physical fatigue levels between testing days.

Unlike the physical fatigue level, significant relationships were observed between the changes in visual memory composite score and the changes in distraction level between day 45 and 50, and the changes in verbal memory composite score and the changes in total symptom score between baseline and day 50 ; however, neither of these relationships were strong. The R^2 and B values for distraction level was .066 and -1.40, which indicates only 6.6% of score change in visual memory can be explained by the change in the distraction level, and one increase in distraction level results in 1.4 point decrease in visual memory. Also, the R^2 and B values for total symptom score was .05 and .247, which indicates only 5% of the score change can be explained by the change in the total symptom score, and one increase in total symptom score

results in .247 increase in verbal memory. Only two statistically significant but weak interactions between changes in ImPACT composite scores and changes in survey/total symptom score data were observed. Therefore, in the current study, changes in the participants' physical and mental condition assessed through the survey and total symptom score do not explain the changes in ImPACT composite score.

Implications of Findings

While utilization of computerized neurocognitive assessments employing pre-participation baseline test followed by a series of post-concussion tests has become a crucial element of the multidisciplinary approach to concussion evaluation and management (Guskiewicz et al., 2004; McCrory et al., 2009), there has been an on-going discussion and debate on the test-retest reliability of computerized neurocognitive tests among clinicians and researchers. This study's findings support the test-retest reliability of one of the most widely used computerized neurocognitive test batteries, ImPACT, by providing acceptable ICC values from baseline to 45 and 50 days. The results of this study also contradict Broglio et al.'s (2007) low test-retest reliability using the same testing intervals. Moreover, the current study's findings agree with other test-retest studies by Millar et al., (2007), Elbin et al. (2011), and Schatz et al. (2010), which suggests that ImPACT can be a reliable tool used for the multidisciplinary approach to concussion management. However, clinicians must be aware that computerized neurocognitive assessments are not intended to be a stand alone diagnostic measure (McCrory et al., 2009).

When clinicians utilize ImPACT for concussion management including return-to-play decisions by comparing baseline and post-concussion data, they should feel more confident in knowing that the ImPACT test has been found to have good test-retest reliability. In the past,

clinicians had difficulty accepting that the changes athletes exhibited on ImPACT post-concussion were truly due to their concussion, rather than a flaw in the ImPACT test. However, only trained clinicians should be responsible for supervising ImPACT tests and reading the results of this computerized neurocognitive test.

Limitations

Several limitations are recognized that may compromise the external validity of the findings from the current study. With respect to the subjects studied in the current study, the most limiting factor is that the participants were physically active college students, not athletes. The ImPACT test is utilized with high school, collegiate and professional athletes, rather than the typical physically active college student. Even though the participants are physically active based on the ACSM recommendation, caution should be taken when attempting to generalize the findings to the athletic population. Also, it is important to note that the current results were obtained from college students and should not be generalized to other age groups, especially to younger populations whose brains are still developing. In addition, while Broglio et al. (2007) assessed the participants' SAT scores, it was not assessed in the current study. Academic achievement of the participants could have affected the result and be a potential confounder.

Another limitation of the current study involves the validity of self-reported data including the participants' mental/physical conditions in testing days and their physical activity level. Regarding the physical activity level, even though the participants were not sedentary population who tend to overestimate the intensity of their physical activity (Duncan et al. 2001), the highest level of intensity in the scale represents activities >7.2 METs, which was not specific enough to differentiate high and vigorous physical activities.

Finally, test takers' level of effort was measured by Rey's 15-item memory test and a self-reported survey. However, due to all three participants who reported an invalid baseline and/or a value greater than 30 on Impulse Control score had a perfect score on the Rey's 15-item memory, the effort assessment in the current study was thought to be not sensitive enough for ImPACT administration.

Suggestions for Future Research

Given the limitation of the current study regarding the sample population, additional data should be collected using the same research design with athletic populations and different age groups to increase external validity. Also, future research would need to investigate the test-retest reliability of ImPACT with different time intervals, especially between the current study and the study of Elbin et al. (2011) whose testing interval was 1-year.

It would be beneficial to examine the test-retest reliability of ImPACT using asymptomatic participants who have a history of multiple concussions. As athletes with concussion history have a higher risk of sustaining another concussion (McCrory et al. 2009), they have a higher chance of utilizing ImPACT. Therefore, obtaining test-retest reliability from this population may enhance the clinical application of ImPACT. In the current study, nine participants had a history of multiple concussions (2 to 4), but the sample size was too small to draw any statistical conclusions.

Lastly, even though it was weak, a significant association of environmental distraction and ImPACT performance was observed in the current study. The effects of test environment on ImPACT performance need to be studied further because in reality the optimal environment may not always be available. For example, in an athletic setting, baseline data tend to be obtained in a group setting that may create some distraction from teammates, whereas post-concussion testing

is more likely to be in an individual setting. It would be beneficial to study the testing environment quality standard for ImPACT in order to ensure test-retest reliability in a real world setting.

Conclusion

This research replicated the study by Broglio et al. (2007) that reported a low test-retest reliability of one of the most widely used neurocognitive testing battery, ImPACT, while assessing the test takers' physical/mental condition and the quality of testing environment. The current study reported ICC values ranging from .60 to .87 with physically active collegiate students who were moderately stressed, mildly fatigued, and slightly distracted by the environment. These findings are in contrast to Broglio et al. who reported ICC values ranging from .23 to .61. The ICC values obtained from the current study is considered to be more reliable because Broglio's et al. had methodological flaws including administering three neurocognitive test batteries successively. According to the current findings, ImPACT has acceptable test-retest reliability when it is administered at baseline, 45 days after baseline, and 50 days after baseline, which support the utilization of ImPACT in concussion management as a part of multidisciplinary approach.

APPENDICES

APPENDIX A: Human Subjects Consent Form
**Examination of Test-Retest Reliability of a Computerized Neurocognitive Test Battery
Informed Consent for Participant**

***For questions regarding this study,
Please contact:***

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***For questions regarding your rights
as a research participant, please contact:***

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Purpose of Study: The purpose of this study is to examine the test-retest reliability of one of the major computerized neurocognitive test batteries used for concussion management (ImPACT) through three test administrations (baseline, 45 and 50 days after the baseline).

Consent: Your participation in the research study is voluntary, as you may choose not to participate at all, or may refuse to answer certain questions, or discontinue participation at any time without penalty.

General Experimental Procedures: You will be administered the ImPACT test battery on a computer three times (baseline, 45 days and 50 days after the baseline). The testing consists of three categories: Demographic, current symptoms, and neuropsychological modules (e.g., word memory, design memory, symbol matching, and so forth). The neuropsychological modules consist of six domains of cognitive functions that form 5 composite scores: Verbal memory, Visual memory, Motor processing speed, Reaction time, and Impulse Control. Prior to each administration of ImPACT, you will be administered the Rey's 15-Item Memory Test, which consists of 15 symbols on a piece of paper for you to memorize them in 30 seconds, and then reproduce them in two minutes. You will also complete a short demographic questionnaire that asks questions pertaining to physical activity level, caffeine and alcohol intake, exercise, and stress level the day of testing. Finally you will complete a very short post-questionnaire that asks questions about whether you were distracted by the surroundings during the testing, faced any technical issues, and understood the test instructions. Testing will be conducted in a quiet computer laboratory under direct supervision. The length of each testing session will be approximately 30 to 40 minutes. Total time for three test sessions will be approximately two hours. ImPACT is not meant to reflect a person's intelligence or level of achievement. Subject's participation may be terminated at the request of the investigator if they are not able to complete all three testing sessions.

Instruction for the participants: Due to possible adverse effects of physical exhaustion on cognitive function, you will be instructed to avoid vigorous exercise and to be well rested for the day of testing.

Possible Risks: There will be little or no discomfort to you. You will be asked to answer questions about learning disabilities and neurological problems. Please be assured that you may choose to not answer certain questions and still continue to participate in this study. All answers are strictly confidential and will not be released to anyone other than those listed in the confidentiality section below.

Benefits: You will not directly benefit from participation in this study. However, the result of this study will contribute to the development of the ImPACT test battery and concussion management.

Compensation: With the completion of participation, you will automatically be entered into a drawing to win a signed Michigan State University basketball or football.

Confidentiality/Anonymity: Participation in this study is completely voluntary. The only people who have access to your answers are the certified athletic trainer, faculty members, HRPP auditors, other funding auditors, or the research integrity office. However, your identity and information recorded during the study will remain confidential. Confidentiality will be protected by: (a) results will be presented in aggregate form in any presentations and publications; and (b) all data will be stored in a computer that has a password necessary to see confidential data. Your confidentiality will be protected to the maximum extent allowable by law. You may also discontinue participation at any time without penalty. Your participation in this research project will not involve any additional costs to you or your health care insurer. Additionally, it may be necessary for the Michigan State University Institutional Review Board to perform a confidential audit of the research data and protocols. Data will be kept under double lock and key for 5 years after the close of the study.

Institutional Contacts: If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 408 W. Circle Dr. Room 207 Olds Hall, MSU, East Lansing, MI 48824.

If you have any concerns or questions about this research study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher (Tracey Covassin at 517-353-2010 or email covassin@msu.edu or regular mail at 105 IM Circle, MSU, East Lansing, MI, 48824). I voluntarily agree to participate in the study.

I, _____ have read and agree to participate in this study as described above. *(Please Print Your Name)*

(Please Sign Your Name)

____/____/____

(Date)

APPENDIX B: Figure A.1. Rey's 15-item Memory Test

Rey's 15-item Memory Test

Please memorize the symbols as many as you can in 30 seconds. You will be asked to reproduce them without worrying about their order.

A

B

C

1

2

3

a

b

c



Figure A.1. (continued)

Rey's 15-item Memory Test Answer Sheet

*Test Taker #*_____ *Date*_____

Please reproduce the 15 symbols as many as you can without worrying about the order.

You have 2 minutes to reproduce.

APPENDIX C: Pre-Testing Survey

Examination of Test-Retest Reliability of a Computerized Neurocognitive Test Battery

Pre-testing Survey

Test Taker # _____ Date _____

The purpose of this survey is to gather information that might affect your performance on ImPACT. Your identity and information recorded during the study will remain confidential. Data will be kept under double lock and key.

1. Please indicate your general exercise intensity, duration, and frequency

Cardiovascular exercise

- Moderate intensity (harder than brisk walking) _____min/week
- Vigorous intensity (e.g., jogging >5mph, sports such as basketball, soccer, tennis, swimming) _____min/week

Resistance exercises (including body weight exercise such as pushups, sit-ups, and squat)

- _____min/session _____days/week

Neuromotor exercise (balance, agility, and coordination exercise)

- _____min/session _____days/week

2. Please rate your current level of stress at this moment?

Not Stressed at all

Very stressed

0 1 2 3 4 5 6 7 8 9 10

3. Did you do vigorous exercise today?

Yes

No

If yes, what exercise and how long? _____

4. Please rate your level of physical fatigue at this moment?

None Exhausted

0 1 2 3 4 5 6 7 8 9 10

5. Did you eat today?

Yes No

6. Please indicate if your food consumption was typical to your normal food consumption?

Not at all Very Typical

0 1 2 3 4 5 6 7 8 9 10

7. Please indicate your alcohol intake in last 12 hours?

Not at all Moderate A lot

0 1 2 3 4 5 6 7 8 9 10

8. Please indicate if your caffeine intake was typical to your normal caffeine intake?

Much less Typical Much more

0 1 2 3 4 5 6 7 8 9 10

Thank you. Please start ImPACT test on the computer screen. After ImPACT test, please complete the post-testing survey

APPENDIX D: Post-Testing Survey

Examination of Test-Retest Reliability of a Computerized Neurocognitive Test Battery

Post-testing Survey

The purpose of this survey is to gather information that might have affected your performance on ImPACT. Your identity and information recorded during the study will remain confidential. Data will be kept under double lock and key.

1. Please rate how distracted you were by the surroundings during the testing?

Not at all

Distracted a lot

0 1 2 3 4 5 6 7 8 9 10

2. Were there any technical issues that affected your performance (e.g. slow mouse response)?

Yes No

If yes, please explain _____

3. Were the instructions clear for the Rey's 15 items memory test?

Yes No

If no, which one/s? _____

4. Were the instructions clear for the ImPACT test?

Yes No

If no, which one/s? _____

5. Please rate your level of effort on taking ImPACT test?

Did not try at all

Tried my best

0 1 2 3 4 5 6 7 8 9 10

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