Cognitive Functioning in Varsity Athletes Following Musculoskeletal Injury

by

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Abstract

**Background:** Research suggests that musculoskeletal injury (MSI) influences cognitive functioning. Cognitive functioning following MSI in athletes is not evaluated currently. **Purpose and Method:** To examine cognitive deficit in athletes following musculoskeletal injuries, the Automated Neuropsychological Assessment Metric (ANAM) was administered to 22 varsity athletes prior to competition and following MSI. A healthy comparison group of 22 athletes was also tested at time intervals matched with the injured group. **Results:** A 2 (Group) X 2 (Time) repeated measures ANOVA revealed significant main effects for time on ANAM subtests of Delayed Code Substitution and Simple Reaction Time. Post-hoc Paired \( t \)-Tests revealed significant improvements in both groups for Simple Reaction Time, and a significant improvement for the comparison group on Match-to-Sample. **Implications:** Athletes with musculoskeletal injuries did not show cognitive deficit post-injury; however, the apparent absence of practice effects on a test of spatial processing and working memory requires further examination.
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Athletes assume a risk of injury by virtue of the nature of the training and intensity involved in competitive sport. An estimate of the frequency of musculoskeletal injuries is provided by a two-year database established between 2000 and 2002. It identified that 73% of the visits to physicians by American collegiate athletes were for musculoskeletal injuries (Steiner, Quigley, Wang, Balint, & Boland, 2005). In contrast, only 10% of visits by non-athlete students were for musculoskeletal injuries. In certain collision sports, like rugby, lower limb musculoskeletal injuries are the most prevalent (Hoskins, Pollard, Hough, & Tully, 2006).

According to Mueller and Maluf (2002) musculoskeletal injury (MSI) is defined as “tissue damage caused by excessive stress resulting in pain or discomfort, impaired function of the tissue, or both”, (p.387). Niemuth, Johnson, Myers, and Thieman (2005) described MSI as “injury or pain to a localized area […] that had required a change or reduction in training, a visit to a health professional, [or] the use of medication on a regular basis”, (p. 16). Structurally speaking, force overload, or injury, occurs when the overall force is of greater degree than the musculoskeletal system can bear (Kibler, Chandler & Stracener, 1992). The apparent variation in injury definitions is problematic; a consensus would help researchers calculate injury rates as well as compare injuries across studies. Orchard and Hoskins (2007) suggested that defining injury in terms of a missed competition (time loss) is the most reliable definition,
and efficiently encompasses most of the existing definitions used in research papers.

In addition to physiological trauma, injury in sport may also result in emotional trauma. A large body of literature exists on the emotional outcomes related to musculoskeletal injuries (e.g., Hardy, 1992; Johnston & Carroll, 2000; Shuer & Dietrich, 1997). Initially, sports injury rehabilitation predominantly focused on the physiological aspects of injury, neglecting the importance of psychological factors (Petitpas & Danish, 1995). In the last two decades, however, there has been increased interest on the integral role that psychological factors play in the injury paradigm, especially in the recovery phase (Cupal, 1998).

The term “psychological impact” is often used when discussing athletic injury. It is an over-inclusive term that includes both emotional and cognitive aspects of experience. The sport science literature suggests that athletes respond to injury both cognitively and emotionally, but does not elaborate on any aspect of cognitive performance. Rather, the theoretical position in the literature is that injured athletes make a cognitive appraisal of the injury and then respond in various emotional, social, and behavioural patterns.

According to Walker, Thatcher, & Lavallee (2007) cognitive appraisal is the process by which a person assesses a situation as stressful. Once a situation has been evaluated, the person may attempt to employ an appropriate coping strategy. In certain cases, a stressful situation can evoke negative emotions and anxiety, both of which may lead to increases in arousal.
Heightened arousal can hinder working memory, diminish the capacity to recall information, negatively impact attentional focus, and decrease cognitive resources available for the task (Just, Keller, & Cynkar, 2008; Jones, Siegle, Muelly, Haggerty, & Ghinassi, 2010). Should an athlete appraise an injury as a stressful event, then potentially increased levels of arousal could tax the athlete’s cognitive resources, leaving him/her fewer reserves for subsequent cognitive tasks. In addition, negative emotions, pain and physiological responses to injury are other factors that could impact arousal and subsequently cognitive resources. After sustaining an MSI, an athlete could have to cope with any of these factors, and conceivably a combination of all of them.

Identifying cognitive consequences of MSI is especially important in collision sports, which require quick decision-making and fast reaction time to avoid contact and potential injury (e.g., quarterback in American football). Any loss of cognitive functioning may render athletes vulnerable to further injury. Second, it brings into question current beliefs and practices involving the neurocognitive testing following mild traumatic brain injury (mTBI). In sports that allow body collisions (deliberate or incidental), mild traumatic brain injuries (mTBI), more commonly referred to as “concussions”, are frequent. They have been defined as traumatically induced alterations in mental status not necessarily resulting in loss of consciousness (Collins et al., 1999). The Center for Disease Control and Prevention reports that 300,000 athletes suffer concussions annually in the United States alone (Moser et al., 2007). In contact
sport, such as amateur ice hockey, concussion incidence rates are the highest of all injuries (Goodman, Gaetz, & Meichenbaum, 2001).

Extensive research has shown decreased neuropsychological test scores following mTBI (Collins et al., 1999, Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Matser, Kessels, Lezak, & Troost, 2001). If MSI is related to post-injury cognitive impairment, it calls into question the causal relation assumed between neurocognitive impairment and sports concussion. How does one discern if it was the brain trauma causing the reduced neurocognitive test scores, or the traumatic nature of sports injury and its psychological sequelae in general? The extent to which response to injury, in general, plays a role in the cognitive impairment observed following sports concussion needs clarification.

Neuropsychological testing of athletes suffering from MSI could reveal how injury in general, and in particular, three specific features of injury (pain, emotion, and injury response) detailed in the literature review, might possibly impact cognitive functioning. Therefore, the purpose of the present study was to examine whether athletes exhibit any cognitive deficit on neuropsychological testing immediately following musculoskeletal injuries sustained during the course of play or practice.

The following chapter addresses the paucity of research to date on evaluating cognition following MSI. Three aspects of injury will be introduced, outlining their possible influence on cognition. The latter half of the chapter will
include a review of mTBI literature as it pertains to sports-related injury, including a review of neuropsychological testing used to evaluate mTBI.
Chapter Two

Literature Review

Musculoskeletal Injuries

An extensive search of several databases, including PubMed, MEDLINE, Scholars Portal, SPORTDiscus and Web of Science, on MSI in sport revealed two trends: There is an extensive body of research on the emotional effects of musculoskeletal injury, and no empirical study of the cognitive effects of musculoskeletal injury. This section examines the psychological impact of MSI on athletes as found in the existing literature. In this case, the term psychological refers to both the emotional and cognitive domains of functioning.

The research on the emotional effects of MSI among athletes has shown that the prevalence of emotional distress and mood disorders increase following athletic injury (Brewer, Linder, & Phelps, 1995). Kvist, Ek, Sporrstedt, and Good (2005) elaborated by stating “psychological responses will always occur in physical trauma or injury and most athletes with injuries will experience negative emotions and lack of self-confidence because of reduced physical ability” (p. 393). Following a decline in self-confidence, some athletes might become apprehensive about re-aggravation of an existing injury, often acting to impair rehabilitation compliance and physical recovery. Mainwaring (1999) reported that of ten athletes suffering from knee injuries, all expressed fear of re-injury, and in some cases this fear decreased their ability to engage in rehabilitation and return to competition.
Emotions exhibited following MSI include depression, anxiety, reduced self-esteem (Leddy, Lambert, & Ogles, 1994), and anger (Hutchison, Mainwaring, Comper, Richards, & Bisschop, 2009). Additionally, an athlete might experience feelings of separation from his/her teammates, as well as guilt for not playing, and a loss of identity (Quakenbush & Grossman, 1994). The increase in negative emotions, and potential subsequent decline in performance, can be long in duration. For example, in Roh and Perna’s (2000) study, the elevation of negative mood occurred at 24 hours post-injury and decreased gradually over 4 weeks post-injury. Although negative emotions are common following injury, the intensity of these emotions and their duration are specific to the individual, based on personal and situational factors (Brewer et al., 1995; Williams, Rotella, & Scherzer, 2001).

In addition to increases in negative mood states after MSI, athletes must also cope with pain. In some cases, the negative emotions or mood have been shown to manifest in a type of “psychophysiological” reaction that can add to and intensify the pain of the injury (Quakenbush & Grossman, 1994; Brewer et al., 1995). Moreover, negative feelings can impede compliance and adherence to the rehabilitative steps necessary following injury, prolonging the injured state (Blumenthal, Williams, Wallace, Williams, & Needles, 1982).

Ultimately, the psychological response of an athlete to MSI depends upon three factors: the athlete’s prior level of physiological functioning; the nature and severity of the injury combined with the duration of rehabilitation,
and finally, the meaning of the disability to the athlete (Quakenbush & Grossman, 1994).

Though there is significant empirical evidence for emotional consequences of injury, there appears to be no empirical investigations reported on cognitive functioning following musculoskeletal injury in sport. That is, whereas athletes are believed to go through cognitive appraisals after injury, cognitive functioning post-injury has not been examined. An extensive literature search found a loosely related study conducted by Walitt, Roebuck-Spencer, Bleiberg, Foster, and Weinstein (2008) in which Automated Neuropsychological Assessment Metrics (ANAM) test scores were compared among patients suffering from fibromyalgia, a control group, and a secondary “Musculoskeletal Pain” control group. The secondary control group in this investigation was comprised of patients with chronic musculoskeletal pain that did not meet the standards for fibromyalgia diagnosis, and injury was not an inclusion criterion. The investigators found no significant differences on ANAM test scores between participants with musculoskeletal pain and healthy controls. Unlike the present study, which seeks to examine the effect of acute injury on cognitive functioning, Walitt et al. (2008) explored chronic pain unrelated to injury.

Proposed Mechanisms of Influencing Cognitive Functioning after Injury

Literature on MSI sequelae was reviewed to examine what happens to an individual subsequent to that type of injury. Three aspects of musculoskeletal injury were identified as possible mechanisms for influencing
cognitive functioning post injury. These aspects are outlined and reviewed below.

**Pain.** The International Association for the Study of Pain defined pain as an unpleasant sensory and emotional experience associated with actual and potential tissue damage or described in terms of such damage (Crofford, 2007). The experience of pain has been identified as a potential confounding factor that may affect the results of neuropsychological testing (Hart, Martelli, & Zasler, 2000). Athletes who suffer from MSI often report experiencing pain (Roh & Perna, 2000). Pain is also a potential symptom of mTBI (Lahz & Bryant, 1996). If pain indeed influences NP testing, then the fact that both MSI and mTBI induces it helps bolster the idea that a general aspect of injury is at play.

The following section will review the current literature on pain, including identification of the role pain may play in influencing neuropsychological testing. Specifically, it examines whether pain directly affects neuropsychological testing, and which aspects of cognitive functioning are most affected by the experience of pain following injury.

The first theory to be explored is that athletes experiencing pain not associated with mTBI show significant differences in neuropsychological test scores when compared to healthy controls. Martelli, Zasler, Bender, and Nicholson’s (2004) review of the literature found strong evidence that pain, independent of mTBI, can induce deficits in cognitive functioning. In fact, cognitive impairment is a common complaint of people suffering from chronic pain. It is also suggested that the areas of cognition likely to be affected by the
experience of pain are attentional capacity, processing speed, memory, and executive functions (Martelli et al., 2004).

Hart et al. (2000) reported that the most common cognitive impairment experienced by patients with chronic pain was related to tasks of memory. To a lesser extent, chronic pain patients performed more poorly on attentional tasks than non-pain controls. Overall, Hart et al. found a negative correlation between degree of pain and cognitive performance. In addition, Farmer et al. (2001) found that patients with migraines had slower, simple reaction times and showed impaired information processing when compared to pain-free controls. They also suffered decreased attentional and memory capacity than controls on neuropsychological testing.

Pain may not have a direct influence on neuropsychological test results, but instead may induce other conditions affecting neuropsychological outcomes. Patients suffering from pain have shown elevated fatigue compared to pain-free controls (Farmer et al., 2001). For instance, sleep disturbance, particularly deprivation, is a common effect of chronic pain (Nicholson & Martelli, 2006) which has been shown to impair cognitive function, with the greatest reduction occurring after acute bouts of sleep deprivation (Martelli et al., 2004; Pilcher & Huffcutt, 1996). Cognitive functioning most affected by sleep deprivation appears to be memory and attention (Durmer & Dingess, 2005).

The exact mechanisms by which pain affects cognitive functioning are unknown. It is postulated that the anterior cingulate cortex (ACC), which helps control pain processing, could impact cognitive functioning through allocation of
attentional resources (Martelli et al., 2004). This theory supports Hart et al.'s (2000) finding of decreased attentional capacity when experiencing pain. Another cause may be stress responses of the hypothalamic-pituitary-adrenocortical (HPA) region of the brain which may have negative implications on hippocampal function and memory (Martelli et al., 2004). The hippocampus has been shown to play an important role in short-term and episodic memory (Manns, Howard, & Eichenbaum, 2007). One proposed theory is that the hippocampus acts as a comparator of present stimuli to previous experience, allowing attention to be directed at the novel features of the present stimuli (VanElzakker, Fevurly, Breindel, & Spencer, 2008). This theory further supports Hart et al.'s (2000) report of the negative impact of pain on memory.

Nicholson and Martelli (2006) document the inconsistency in empirical findings with respect to the association between pain and cognitive deficit following sports-related injury. Their review of the literature revealed that some pain sufferers do not experience any cognitive decline. Similarly, a study by Walitt et al. (2008) compared ANAM test results of fibromyalgia patients with healthy controls and reported no significant differences in short-term memory, cognitive efficiency, concentration, or reaction time between the two groups. Furthermore, there was no correlation between the severity of fibromyalgia symptoms and cognitive function. They concluded that any cognitive impairment connected to chronic pain is most likely a “subjective phenomenon”.

Current literature appears to indicate that pain affects cognitive functioning, although it is unknown exactly how or to what degree. In addition to
lack of understanding of the mechanics of pain on cognition, results are difficult to interpret because of study design and methodology. For example, in Farmer et al.’s (2001) study, investigators failed to control for previous history of traumatic brain injury, which could be a confounding factor. Thus, further research is needed to assess the impact of pain on neuropsychological functioning, particularly acute pain experienced following traumatic injury acquired in sport.

**Injury response and its impact on cognition.** A second possible mechanism influencing the results of NP testing might be the body’s response to sustaining an injury. There are two characteristics of injury response that are important to cognition. First is the autonomic nervous system (ANS). The ANS is responsible for maintaining and regulating blood pressure, pulse, respiration, body temperature, and heart rate (Crofford, 2007). The sympathetic nervous system, a branch of the ANS, is activated immediately when exposed to a stressor, and is responsible for the release of epinephrine and norepinephrine (Herbert et al., 1994). The aforementioned hormones are involved in the “fight or flight” response and increase body functions that the ANS is responsible for regulating (e.g., heart rate, blood pressure, etc.). Research has connected sympathetic nervous system activation with impaired performance on cognitive and sensorimotor tasks (Christianson, 1992). Specifically, increased heart rate and blood pressure can blunt sensory reception and compromise event encoding processes necessary for memory (Richards & Gross, 1999).
Physical injury also results in the release of glucocorticoids from the adrenal gland, specifically cortisol, which target inflammation and swelling. With marked physical stress (e.g., injury) comes an accompanied hypersecretion of cortisol by the adrenal gland through secretion of norepinephrine by sympathetic ganglionic neurons (Holden-Lund, 1988). On tests of working memory, high doses of cortisol administration tend to decrease performance (LaBar & Cabeza, 2006).

Surprisingly, increased cortisol levels result in further ANS activation (Crofford, 2007). This suggests a cyclical pattern of sorts; that injury begets cortisol release from the adrenal gland which is under control of the ANS, which begets supplementary ANS arousal.

Further to the above, an interesting analysis of criminal reports found that victims who were physically assaulted gave poorer descriptions of events than victims who were uninjured (Christianson, 1992). In those cases, the presence of an injury led to poorer memories of the crimes.

**Emotional impact on cognition.** A third proposed mechanism of influence on NP testing outcomes is the emotional response to suffering an injury. As mentioned earlier, musculoskeletal injury can often evoke an emotional response. Normally, pain has two emotional elements: the unpleasantness of the sensation and the negative feelings that follow, for instance depression, anger, and fear. These two elements can be referred to as primary and secondary pain affect, respectively (Crofford, 2007).
It has been well documented that emotions can influence cognitive functioning (Phelps, 2004.) Early research on emotions sought to test memory in differing emotional states. Results revealed that memory retrieval is hampered when recall is attempted in a different emotional state than when the memory was encoded (Bower, Sahgal & Routh, 1983). Also, memory both prior to and after an emotional event has been shown to be impaired (Christianson, 1992). In these instances, the ability to recall detailed instructions was also impaired.

Emotional stress appears to increase activation of the hypothalamic pituitary adrenal axis through secretion of corticotrophin-releasing hormone and arginine vasopressin from the paraventricular nucleus of the hypothalamus, which subsequently stimulates the anterior pituitary to release adrenocorticotropin. Emotional stress begins to parallel the effects of the physical stress of injury as adrenocorticotropin stimulates the release of cortisol from the adrenal cortex (Crofford, 2007). This emotionally induced release of adrenal stress hormones is of importance because it’s been shown to alter performance on learning and memory tasks (LaBar & Cabeza, 2006).

Indirectly through cortisol release, much like the injury response, emotions such as fear, anger, and panic, can induce activation of the ANS (Crofford, 2007). Specifically, anger generates increases in heart rate and blood pressure, and the cardiovascular pattern during anger resembles the pattern during dynamic exercise (Sinha, Lovallo, & Parsons, 1992).
Also of importance is not simply the fact that there is often an emotional response to injury, but also the way athletes cope with these emotions. One study showed that undergraduate students were found to inhibit emotionally expressive behaviour about twenty-five percent of the time (Richards & Gross, 1999). Later the same study was able to show that those who actively suppressed their emotions performed more poorly on memory tests than those who did not. In those cases, emotional suppression increased sympathetic nervous activity, and it has been shown that young athletes tend to suppress their emotions, especially males (Shepard, 2009).

Lastly, theories on emotional arousal seem to espouse the notion of finite attentional resources. During periods with low levels of arousal, more cognitive resources are available to an individual. When increases in arousal are paired with a cognitive task, “mental efficiency” begins to decline (Christianson, 1992). That is, as more attention is appropriated by increasing levels of emotional arousal, less attentional resources are available for cognitive tasks.

**Mild Traumatic Brain Injury (mTBI)**

This section provides an overview of mTBI, and specifically the testing used to evaluate cognitive performance following mTBI. Although MSI and mTBI are typically unrelated injuries, the method used to evaluate neurocognitive function following MSI in this study was borrowed from the existing testing protocol currently used to examine cognitive functioning following mTBI in sport (Erlanger et al., 2001; McCrea et al., 2003). As such, a brief review of mTBI and specific testing used to assess it is warranted.
Mild traumatic brain injury is the result of impact to the head or an action that creates sudden acceleration and deceleration of the brain inside the skull (Moser et al., 2007). The risk for mTBI is especially great for athletes in collision sports (Powell, 2001). It is an “invisible” injury, meaning that it does not result in any visible signs (e.g., swelling, bruising) of the injury (Bloom, Horton, McCrory, & Johnston, 2004). Although there are no visible signs of the injury, there are symptoms, particularly somatic, emotional, and/or cognitive.

Common somatic symptoms, such as headaches, can last for a day or longer and often do not manifest until hours post-injury (Ropper & Gorson, 2007). Other somatic symptoms include dizziness and fatigue (Hutchison et al., 2009). Typical emotional symptoms include depression (Mainwaring, Hutchison, Bisschop, Comper, & Richards, 2010) and anxiety (Echemendia & Julian, 2001). Deficits in cognitive functioning are characterized by an inability to concentrate, process information, integrate thought processes, as well as word-finding difficulties (Hall, Hall, & Chapman, 2005). Following an mTBI, patients can experience reductions in information-processing speed, attention, and reaction time (Collie, Makdissi, Maruff, & McCrory, 2006). Declines in memory function are also present, with athletes reporting difficulty recalling the moments leading to the injury, a form of retrograde amnesia (Ropper & Gorson, 2007). Psychologists aim to evaluate these deficits when managing mTBI.

Certain traditional neuropsychological tests, especially those that deal with processing and reaction time, have been shown to be sensitive to mTBI (Cernich, Reeves, Sun, & Bleiberg, 2007). Tests in the ANAM system have
been designed to assess attention and concentration, working memory, mental flexibility, spatial processing, cognitive processing efficiency, memory recall, mood, fatigue level, and psychomotor performance, and are therefore also sensitive to the effects of mTBI (Bleiberg, Kane, Reeves, Garmoe, & Halpern, 2000; Cernich et al., 2007; Reeves, Winter, Bleiberg, & Kane, 2007). ANAM was initially designed for military purposes, testing the psychological functioning of military personnel in response to antidote use prior to possible chemical weapon attacks (Reeves et al., 2007). The resulting product today is a library of test modules that can be configured into batteries organized for varying clinical and research purposes. One such battery, the ANAM Sports Medicine Battery (ASMB), has been used extensively to examine the NP sequelae of sports concussion. The research clearly shows a neurocognitive decline post concussion that abates, typically, within 7-10 days (Echemendia, 2006). The ASMB allows athletes to be tested quickly prior to their season so that a baseline is on record in the event of a concussion.

**Summary and Hypotheses**

The current study postulates that musculoskeletal injuries will be associated with cognitive impairment as measured by the NP test battery, ASMB. The purpose of the review of literature was to examine typical athletic experiences following MSI, as well as outline aspects of MSI that could impact NP testing.

Presently, there is research outlining the emotional consequences of musculoskeletal injury (Brewer et al., 1995). There is evidence to suggest that
athletes employ cognitive appraisals post-injury (Knardahl, 2005). That is, once athletes are injured they assess the situation as stressful and use appropriate coping strategies. Currently there is no established and standardized testing protocol to evaluate cognitive functioning post-MSI. This is due to the fact that cognition is not currently believed to be affected by MSI. Empirical research on the role MSI may play in impairment of normal cognitive functioning may be beneficial in return-to-play decisions for athletes. For example, if athletes with MSI have been allowed back to competition without evaluation of their cognitive functioning they may be placed at increased risk of further injury, particularly in high-paced collision sports requiring fast reaction time. Also, it may shed light on the extent to which general mechanisms of injury influence cognitive performance post mTBI, potentially increasing our understanding of the nature of injury and the impact on cognition.

Research on mTBI demonstrates that cognition is impaired post-injury. However, the exact manner of impairment has not as of yet been established. This study attempted to ascertain if MSI is associated with similar cognitive declines as seen with mTBI in an effort to give insight on possible factors contributing to the post-concussive cognitive decline. This study has outlined three aspects of MSI that could potentially affect the outcomes of NP testing: the experience of pain and the athlete’s response to pain, the physiological response to injury, and the negative emotional responses to injury.

Pain may be a symptom of both MSI and mTBI. For this reason, if athletes with MSI are shown to demonstrate similar cognitive deficits as those
with mTBI, then pain might be influencing that decline, should it be shown that both groups were experiencing pain. At present, the literature is ambiguous at best with respect to how exactly, and to what extent, pain affects cognitive function.

Evidence was provided that showed the physiological response to injury induces certain physiological changes that could impact cognitive functions. Events such as the release of cortisol have been shown to hinder working memory.

Negative emotions often follow the sustaining of an athletic injury, and there is evidence to suggest that negative emotions could also influence cognitive functioning. Much like the theory of cognitive appraisal, negative emotions likely influence cognitive functioning by increasing levels of arousal.

The literature review has clearly established that, following MSI, the athletes may experience psychological consequences, typically negative emotional reactions to injury. Other than the assertion that athletes make a cognitive appraisal after injury, there is no empirical work to evaluate the cognitive impact of MSI. Examining neurocognitive sequelae of MSI is important for return-to-play decisions for injured athletes, but also has particular relevance to the sports mTBI literature. As discussed, the neurocognitive decline following sports concussion is assumed to be strictly related to brain trauma. This study aimed to explore the influence of musculoskeletal injury in general on the post-injury cognitive functioning of athletes.
Hypotheses. The purpose of this study was to examine whether athletes exhibit cognitive deficit immediately following musculoskeletal injuries sustained during varsity practice or competition through the administration of a specific neuropsychological test battery (ANAM), which is typically used for the assessment of cognitive functioning post mTBI. In order to determine if there was a significant deficit in cognitive functioning in athletes with musculoskeletal injuries, neuropsychological test scores were compared to their baseline (pre-injury) scores, as well as test scores from a comparison group. ANAM provides three different scores, those of accuracy, speed of response, and number of correct answers over a given unit of time (throughput). As throughput is a combination of the first two scores, it was chosen as the dependent variable.

The athletes in this study had already completed baseline NP tests collected as part of the mandatory requirements and ongoing research on concussion at the University of Toronto. Baseline testing is conducted in the athlete’s first year of participation, and subsequent testing occurs if a concussion is sustained during the season.

There were 4 hypotheses for this study and four outcome measures related to each hypothesis:

Hₐ₁: There would be a significant decline in cognitive performance within the MSI group on four ANAM subtest scores which measure selected aspects of cognition.
Alternative hypothesis 1-a tests spatial processing and working memory as measured by the Match-to-Sample (MSP) subtest of ANAM (see Method section for details of ANAM)

- Alternative hypothesis 1-b tests learning, encoding, and visual scanning as measured by the Code Substitution subtest (CDS)
- Alternative hypothesis 1-c tests learning and encoding as measured by the Delayed Code Substitution subtest (CDD)
- Alternative hypothesis 1-d tests visuo-motor response time as measured by the Simple Reaction Time subtest (SRT)

H$_{A2}$: There would be a significant difference in cognitive performance on ANAM subtest scores between groups on the second assessment (i.e., post-injury for the injured group and time 2 for the comparison group) on Match-to-Sample (H$_{A2}$-a), Code Substitution (H$_{A2}$-b), Delayed Code Substitution (H$_{A2}$-c), and Simple Reaction Time (H$_{A2}$-d) subtests.

H$_{03}$: There would be no significant difference in ANAM subtest scores between groups on baseline testing on Match-to-Sample (H$_{A3}$-a), Code Substitution (H$_{A3}$-b), Delayed Code Substitution (H$_{A3}$-c), and Simple Reaction Time (H$_{A3}$-d) subtests.

H$_{04}$: There would be no significant difference in ANAM subtest scores across time in the comparison group on Match-to-Sample (H$_{A4}$-a), Code Substitution (H$_{A4}$-b) Delayed Code Substitution (H$_{A4}$-c) and Simple Reaction Time (H$_{A4}$-d) subtests.
Chapter Three

Method

Participants

Twenty-three athletes who sustained musculoskeletal injuries were recruited to participate in the study. Musculoskeletal injury was operationally defined as 1) a loss of time, which necessitated the removal of the athlete from at least one competition or practice, and 2) a loss of function. Physicians who diagnosed injury did so using both a structural and functional definition of injury, but this heuristic varied with physicians. One injured participant was excluded from the study as this athlete did not satisfy the criteria for acute injury. It was found that the injury sustained was actually a re-aggravated, pre-existing injury. Consequently, this athlete's time-matched comparison was removed from analysis, reducing both groups to 22. All injured participants completed testing in the concussion testing lab at the University of Toronto, Faculty of Physical Education and Health. Minor injuries included muscle contusions, strains and ligament sprains. More severe injuries included ligament tears and one athlete dislocating an elbow. Demographic data are outlined in Table 1 on page 27.

As mentioned, the University of Toronto athletic department mandates that athletes competing in sports which are deemed by the research group to be at risk of concussion are required to undergo baseline testing. The current study aimed to recruit athletes from the same sports. These sports included: basketball, ice hockey, field hockey, football, volleyball, rugby, lacrosse, soccer and mountain biking. They were recruited into either an injured group of
student-athletes, or a comparison group of healthy student-athletes, uninjured at the time of testing. (See Procedures for recruitment method.)

Sixty-eight percent of the injured group were male (n = 15), compared 32% female (n = 7). Consequently the comparison group was stratified in the same manner. The mean age of the injured group ($M = 20.14, SD = 1.91$) was not significantly different from the mean age of the comparison group ($M = 20.36, SD = 1.89$), $t(42) = .397, p = .694$.

**MSI group.** Twenty-two injured athletes were recruited to the MSI group. Inclusion criteria for the MSI group stated that athletes must have sustained an injury during practice or competition, and post-injury testing must have been conducted within 72 hours of sustaining the injury. The exclusion criterion was the sustaining of an mTBI. Athletes were referred to the study by their team therapist or doctor. In each case, the athlete had already been through baseline testing as required for their sport at the university. These archived baseline data were used with the results of testing after injury to derive two time points of testing: pre- and post-injury (time 1 and 2 respectively).

**Comparison group.** Twenty-two athletes, healthy at the time of recruitment, were recruited for the comparison group. As with the MSI group, each athlete in the comparison group had already undergone baseline testing prior to their participation in that sport, as part of the University of Toronto Concussion Study protocol. Fifteen of these athletes’ results were obtained from this larger pool of existing baselined athletes. Seven athletes were recruited to complete the group. These comparison group athletes were
matched with the MSI group on the time lapse between baseline testing and assessment post-injury. Specifically, the time between each injured athlete’s baseline and injury was measured, providing an individual time lapse. Fifteen comparison group athletes already had a second assessment (re-baseline) that matched time lapses with 15 injured subjects. Seven additional comparison group athletes were re-tested to provide a second baseline with a similar lapse in time to a matched injured counterpart.

Time matches for the comparison subjects were made within plus or minus one day for all baseline-to-post-injury assessment lapses of less than 1 month. Baseline-to-post-injury time lapses of 1 to 3 months were matched within plus or minus two days. Baseline-to-post-injury assessment time lapses of more than 3 months but less than 5 years were matched within plus or minus two months.
<table>
<thead>
<tr>
<th></th>
<th>MSI</th>
<th>COMPARISON</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 22</td>
<td>n = 22</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>15 (68%)</td>
<td>15 (68%)</td>
</tr>
<tr>
<td>Female</td>
<td>7 (32%)</td>
<td>7 (32%)</td>
</tr>
<tr>
<td><strong>Age (Years)</strong></td>
<td>20.1 (1.91)</td>
<td>20.3 (1.89)</td>
</tr>
<tr>
<td><strong>Sport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Football</td>
<td>11 (50%)</td>
<td>7 (32%)</td>
</tr>
<tr>
<td>Hockey</td>
<td>4 (18%)</td>
<td>5 (23%)</td>
</tr>
<tr>
<td>Rugby</td>
<td>3 (14%)</td>
<td>0</td>
</tr>
<tr>
<td>Lacrosse</td>
<td>1 (4.5%)</td>
<td>0</td>
</tr>
<tr>
<td>Soccer</td>
<td>1 (4.5%)</td>
<td>2 (9%)</td>
</tr>
<tr>
<td>Basketball</td>
<td>1 (4.5%)</td>
<td>3 (14%)</td>
</tr>
<tr>
<td>Volleyball</td>
<td>1 (4.5%)</td>
<td>3 (14%)</td>
</tr>
<tr>
<td>Field Hockey</td>
<td>0</td>
<td>2 (9%)</td>
</tr>
<tr>
<td><strong>Baseline – Time 2 Lapse</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 15 days</td>
<td>5 (23%)</td>
<td>5 (23%)</td>
</tr>
<tr>
<td>&lt; 3 months</td>
<td>4 (18%)</td>
<td>3 (14%)</td>
</tr>
<tr>
<td>&lt; 6 months</td>
<td>3 (14%)</td>
<td>3 (14%)</td>
</tr>
<tr>
<td>&lt; 1 year</td>
<td>1 (4.5%)</td>
<td>2 (9%)</td>
</tr>
<tr>
<td>&lt; 2 years</td>
<td>2 (9%)</td>
<td>2 (9%)</td>
</tr>
<tr>
<td>&lt; 3 years</td>
<td>5 (23%)</td>
<td>5 (23%)</td>
</tr>
<tr>
<td>&lt; 4 years</td>
<td>1 (4.5%)</td>
<td>1 (4.5%)</td>
</tr>
<tr>
<td>&lt; 5 years</td>
<td>1 (4.5%)</td>
<td>1 (4.5%)</td>
</tr>
<tr>
<td><strong>History of Concussion</strong> (#)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>12 (54%)</td>
<td>10 (45%)</td>
</tr>
<tr>
<td>1</td>
<td>7 (32%)</td>
<td>5 (23%)</td>
</tr>
<tr>
<td>2</td>
<td>3 (14%)</td>
<td>4 (18%)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>2 (9%)</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>1 (4.5%)</td>
</tr>
</tbody>
</table>
Measures

A demographic data questionnaire was designed to obtain age, sex, height, weight, program of study, varsity team, and previous history of injury (see Appendix A). Participants in both the injured and comparison groups were administered the neuropsychological test battery prior to participation in their respective sports programs. The cognitive test battery was comprised of the computer based ANAM tests described below.

**Automated Neuropsychological Assessment Metrics (ANAM).** The ANAM Sports Medicine Battery (ASMB) is the version of ANAM designed to assess baseline and recovery from mTBI (Reeves et al., 2007). The ASMB Version 4 consists of tests of simple reaction time, normal and delayed code substitution, sample matching, and spatial processing (Cernich et al., 2007).

ASMB has undergone numerous revisions since its development, and therefore some of its subtests have been altered or even discontinued from use. There are four subtests that have remained constant within ASMB versions since the beginning of data collection for the current research project. These specific subtests of ASMB are described by Reeves et al. (2007) and include the following: Simple Reaction Time, which involves responding to a visual stimulus as quickly as possible with the computer mouse; Sample Matching in which an image is briefly presented and then the subject is required to choose its match from two subsequent images; and Code Substitution (Immediate and Delayed), which requires the subject to learn a set of symbols and their associated numbers. In Code Substitution, the subject is quizzed directly after
viewing the correct legend of symbols and numbers. In the delayed version, the proposed symbol/number pairing does not immediately follow a viewing of the legend. That is, the athletes is provided the symbol/number pairings to view on the first administration of the test, and then, in the subsequent administration, the second to last test to be administered, the athlete is asked to recall the number associated with each presented symbol without any prompts or viewing of a legend.

The ANAM system is designed to meet the need for serial testing and precision measurement of cognitive processing in a variety of contexts that include neuropsychology, fitness for duty, and sports medicine (Reeves et al., 2007). ANAM has been shown to be a valid measure with correlations to more traditional paper and pencil tests, such as the Trail Making Test and Paced Auditory Serial Addition Test (Cernich et al., 2007). Correlations with a traditional neuropsychological test used in sports concussion, Digit Symbol, ranged from .38 to .54 (r, SRT = .38, MSP = .38, CDS = .54). ANAM has also been shown to be a reliable measure, with moderate to good test-retest reliability, ranging from .38 to .66 (r, T1-T2; SRT = .38, SPD = .60, MSP = .66), with moderate to strong internal consistency (Cernich et al., 2007). The specific outcome measures that Cernich et al. (2007) reported were simple reaction time (SRT), spatial processing (SPD), and match-to-sample (MSP).

ANAM tests have several benefits. First, they allow timing to the nearest millisecond. Also, the ANAM test can often be administered in 15 minutes or less. Furthermore, ANAM testing is sensitive to mTBI, as well as less vulnerable
to the practice effects that are commonly observed with traditional
europsychological tests (Reeves et al., 2007). In addition to these benefits,
ANAM helps with more subjective problems associated with diagnosing mTBI.
Often concussed athletes will deliberately withhold revealing symptoms
associated with mTBI for fear of missing competition time (Moser et al., 2007).
Individuals who have become adept at masking the signs of mTBI have more
difficulty masking these symptoms on ANAM testing, especially if they are
unfamiliar with the specific aspects being assessed. In a study conducted by
Fazio, Lovell, Pardini, and Collins (2007), participants were separated into a
symptomatic concussed group, a concussed group of participants who declared
themselves to be asymptomatic, and a comparison group. All participants
underwent computerized neuropsychological testing. The asymptomatic group
scored significantly lower than the comparison group, indicating that although
they claimed to have no symptoms, they still showed lowered scores. This
emphasizes the important role computerized neuropsychological testing can
play in identifying mTBI progression and recovery regardless of subject-
reported symptomatic status. For MSI, the benefits of computerized
neuropsychological testing are similar. Not unlike athletes potentially masking
symptoms, these are a group of athletes who may have cognitive impairment
when it is believed they do not.

Procedure

Participants were recruited through the help of sports physicians and
team athletic therapists at the University of Toronto MacIntosh Sports Medicine
Clinic. Prior to the respective sports' season, a meeting was held with the athletic therapists and team doctor for each varsity sport to outline and review the protocol for referring injured athletes. All athletes completed an informed consent form after reading an information letter detailing the aims of the study as well as requirements for participating (see Appendix B). Prior to their respective competition season, each athlete was scheduled to visit the clinic and complete the ASMB test battery to provide the researchers with their baseline data. This computerized data was stored on a secured hard drive in the research lab.

Upon injury, the team athletic therapist or physician evaluated the injury, determining its nature and severity. This study operationally defined MSI as one that necessitated a physician or therapist to remove the athlete for a minimum of one practice or competition. Once this criterion was met, the athlete was then referred for participation in the current research project to undertake NP testing within 72 hours. The same ASMB test battery was administered post-injury.

To facilitate concentration, participants were administered the ASMB portion of the test alone in a quiet room. The team physician evaluating the injured athlete was blinded to the results of the neuropsychological testing. All injury and re-baseline testing was completed at the concussion testing lab at the University of Toronto, Faculty of Physical Education and Health.

**Research Design and Analysis**

Conventional mTBI design involves baseline neuropsychological testing of athletes without history of significant traumatic brain injury prior to beginning
their competition season (Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Mrazik et al., 2000). If pre-tested athletes sustain an mTBI during play, they are promptly re-tested to document any neuropsychological changes. The testing continues in a serial fashion determined by each research group. The current study mirrored the same paradigm design. A quasi-experimental, 2 (Group) x 2 (Time) factorial design was used (see Table 2). The MSI group was compared to itself, at time 1 and time 2, as was the comparison group (within-subjects). Then the MSI injury group was also compared to the time-matched comparison group at time 1 and time 2 (between-subjects). An alpha level of .05 was set as to establish significance.

Table 2 - 2 (Group) x 2 (Time) Factorial Research Design

<table>
<thead>
<tr>
<th>Group</th>
<th>Time₁</th>
<th>Time₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison Group (n = 22)</td>
<td>Baseline</td>
<td>Re-Baseline</td>
</tr>
<tr>
<td>MSI Group (n = 22)</td>
<td>Baseline</td>
<td>Post-Injury</td>
</tr>
</tbody>
</table>

Outcome Variables. Four outcome variables were used to test cognitive functioning. The descriptions for the outcome variables were taken from Walitt et al. (2008). Match to sample (MSP) measures short-term working memory. Code substitution (Immediate and Delayed; CDS + CDD) measures the ability to learn, visual scanning, and working memory. Simple reaction time (SRT) provides a measure of pure reaction time. It also measures motor response time. Throughput scores of each subtest were used. Throughput is
the number of correct scores over a given unit of time. A higher throughput means greater accuracy rates over that unit of time, and demonstrates better cognitive performance.

To determine if there was a significant difference in mean scores obtained post injury compared to baseline SPSS version 16.0 was used to run a 2 (group) x 2 (time) repeated measures analysis of variance (ANOVA).

Null hypothesis 1 stated that there will be no significant change in performance as measured by ASMB throughput scores of Simple Reaction Time, Immediate and Delayed Code Substitution, and Match-to-Sample subtests within the MSI group at time 2 compared to time 1. This hypothesis was examined with ANOVA results and pairwise comparisons.

Null hypothesis 2 stated that there will be no significant difference in performance as measured by ASMB throughput scores of Simple Reaction Time, Immediate and Delayed Code Substitution, and Match-to-Sample subtests between the MSI group at time 2 and the comparison group at time 2. This hypothesis was tested with ANOVA results and pairwise comparisons.

Null hypothesis 3 stated that there will be no significant difference in performance as measured by ASMB throughput scores of Simple Reaction Time, Immediate and Delayed Code Substitution, and Match-to-Sample subtests between the MSI group, and comparison group at time 1. This hypothesis was tested with ANOVA results and pairwise comparisons.

Null hypothesis 4 stated that there will be no significant change in performance as measured by ASMB throughput scores of Simple Reaction
Time, Immediate and Delayed Code Substitution, and Match-to-Sample subtests within the comparison group at time 2, compared to time 1. This hypothesis was tested with ANOVA results and pairwise comparisons.

Power calculations were run for each of the four subtests. Using an 80% probability of correctly rejecting the null hypothesis, a sample size of 18 was calculated for Match-to-Sample (MSP), a sample size of 27 was calculated for Code Substitution (CDS), a sample size of 24 was calculated for Delayed Code Substitution (CDD), and a sample size of 30 was calculated for Simple Reaction Time (SRT). When power was reduced to 70% probability of correctly rejecting the null hypothesis, more favorable sample sizes of 14 for MSP, 20 for CDS, 18 for CDD, and 23 for SRT were calculated. As mentioned in the Participants section, 23 athletes were originally, successfully recruited for the MSI group (one later had to be excluded from analysis). The N of 30 subjects was not achieved due to time constraints and this limitation is addressed in the Discussion section.

**Ethical Considerations**

This project was approved by the University of Toronto Office of Research Services ethics protocol #22768. The confidentiality of information was ensured through use of identification numbers on all data records. Only the research team was aware of the identities of the participants. No identifying information has been, or will be, published or presented. Participant information is stored on a password protected computer in the laboratory. Only the research team had access to the data.
Although each subject had already received explanations of both the consent process and the tests to be conducted, the investigators reviewed the procedures with the athletes prior to commencing testing. The investigators ensured that participants understood the purpose and participation requirements of study, and informed participants that involvement in the study did not impact their playing status on their respective teams. All participants were allowed to withdraw their consent and discontinue participation at any time during the course of this study for any reason without penalty. No participants withdrew their consent, or discontinued their participation.
Chapter Four

Results

The purpose of the study was to determine if MSI influenced cognition as measured by neuropsychological testing immediately post injury. There were four hypotheses that were tested with repeated measures analysis of variance (ANOVA) and post-hoc, 2-tailed, paired samples t-tests. Each hypothesis is restated below in relation to the associated results.

ANOVA for Match-to-Sample, missed demonstrating a significant interaction by two one-hundredths ($p = .052$). Therefore, a 2-tailed, paired samples t-test was used to examine if a significant effect had in fact occurred.

Repeated measures ANOVA revealed no significant main effect for time for the Match-to-Sample subtest, $F (2, 42) = .674$, $p = .416$. (See Figure 1.1). A post-hoc paired sample t-test revealed that scores for the Match-to-Sample subtest were not significantly different in the injured group at Time 1 (see Table 3 for means and standard deviations) in contrast to Time 2, $t(21) = .713$, $p = .484$. (See Figure 1.1). However, paired t-test results showed that scores for the Match-to-Sample subtest were significantly lower in the comparison group at Time 1 than Time 2, $t(21) = -2.529$, $p = .020$. (See Figure 1.1). Therefore, hypothesis 1-a, that there would be significant decline within the MSI group at Time 2 compared to Time 1 was not supported. In contrast, hypothesis 4-a, that there would be no difference within the comparison group at Time 2 compared to Time 1, was not supported by this result.
Repeated measures ANOVA revealed no significant main effect for group $F(2, 42) = .679, p = .414$, for Match-to-Sample, and no interaction was found, $F(2, 42) = 4.016, p = .052$. (See Figure 1.1). Therefore, hypothesis 2-a, that there would be a significant difference between the MSI and comparison group at Time 2 was not supported; but hypothesis 3-a, that there would be no significant difference between the MSI and comparison group at Time 1 was supported. Levene’s test indicated equal variances for MSP at both baseline ($F = .679, p = .414$) and post-injury ($F = .807, p = .374$).

Repeated measures ANOVA revealed no significant main effect for time for the Code Substitution subtest, $F(2, 42) = 2.848, p = .099$, and thus hypothesis 1-b, that there would be significant decline within the MSI group at Time 2 compared to Time 1 was not supported; but null hypothesis 4-b, that there would be no difference within the comparison group at Time 2 compared to Time 1 was supported. (See Figure 1.2).

Repeated measures ANOVA revealed no significant main effect for group $F(2, 42) = .029, p = .865$, for Code Substitution, and no interaction was found, $F(2, 42) = .870, p = .356$. Therefore, hypothesis 2-b that there would be a significant difference between the MSI and comparison group at Time 2 was not supported; but null hypothesis 3-b, that there would be no significant difference between the MSI and comparison group at Time 1 was supported. (See Figure 1.2). Levene’s test indicated equal variances for CDS at baseline ($F = .822, p = .370$) but not at post-injury ($F = 4.853, p = .033$).
Repeated measures ANOVA revealed a significant main effect for time for the Delayed Code Substitution subtest, $F(2, 42) = 4.164$, $p = .048$, indicating a poorer performance at Time 2. However, paired t-test results showed that injury group scores for the CDD subtest at Time 1 were not significantly different than scores at Time 2, $t(21) = 1.288$, $p = .212$. Thus hypothesis 1-c, that there would be significant decline within the MSI group at Time 2 compared to Time 1 was not supported. (See Figure 1.3). Likewise, paired t-test results showed that scores for the CDD subtest in the comparison group were not significantly different at Time 1 compared to Time 2, $t(21) = 1.589$, $p = .127$. (See Figure 1.3) As anticipated, hypothesis 4-c, that there would be no difference within the comparison group at Time 2 compared to Time 1 was supported. (See Figure 1.3).

Repeated measures ANOVA revealed no significant main effect for group, $F(2, 42) = 1.119$, $p = .296$, for Delayed Code Substitution, and no interaction was found $F(2, 42) = .315$, $p = .577$. (See Figure 1.3). Therefore, hypothesis 2-c, that there would be a significant difference between the MSI and comparison group at Time 2 was not supported; but hypothesis 3-c, that there would be no significant difference between the MSI and comparison group at Time 1 was supported. Levene’s test indicated equal variances for CDD at both baseline ($F = .064$, $p = .801$) and post-injury ($F = .459$, $p = .502$).

Repeated measures ANOVA revealed a significant main effect for time for the Simple Reaction Time subtest, $F(2, 42) = 9.654$, $p = .003$, indicating a better performance at Time 2. Paired t-test results showed that injury group
performance for the Simple Reaction Time subtest was significantly worse for the injured group at Time 1 compared to Time 2, \( t(21) = -2.187, p = .040 \). Thus hypothesis 1-d, that there would be significant \textit{decline} within the MSI group at Time 2 compared to Time 1 was not supported (See Figure 1.4). Paired t-test results showed that comparison group performance for the Simple Reaction Time subtest was significantly worse at Time 1 compared to Time 2, \( t(21) = -2.308, p = .031 \). Subsequently, hypothesis 4-d, that there would be no difference within the comparison group at Time 2 compared to Time 1 was not supported. (See Figure 1.4).

Repeated measures ANOVA revealed no significant main effect for group, \( F (2, 42) = .180, p = .673 \) for Simple Reaction Time, and no interaction was found \( F (2, 42) = .256, p = .615 \). (See Figure 1.4). Therefore, hypothesis 2-d, that there would be a significant difference between the MSI and comparison group at Time 2 was not supported; but null hypothesis 3-d, that there would be no significant difference between the MSI and comparison group at Time 1 was supported. Levene’s test indicated equal variances for SRT at both baseline (\( F = 2.240, p = .142 \)) and post-injury (\( F = .329, p = .569 \)). Table 3 on page 46 summarizes the means of the subtests for both groups. See Appendix “D” for a table summary of the ANOVA and paired samples \( t \)-test results.

Only one subtest, CDS at post-injury, violated Levene’s test. Although analysis of variance is robust to violations of equal variance, and the same sample managed to satisfy Levene’s criteria at all other time points, this violation is a limitation of the analysis.
Figure 1.1. Match-to-Sample mean scores ($N = 22$).

Figure 1.2. Code Substitution mean scores ($N = 22$).
Figure 1.3. Delayed Code Substitution mean scores ($N = 22$).

Figure 1.4. Simple Reaction mean scores ($N = 22$).
Table 3 - Means (Standard Deviations) of Subtest Scores

<table>
<thead>
<tr>
<th></th>
<th>Time 1</th>
<th>Time 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comparison Group n = 22</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSP</td>
<td>41.92 (15.45)</td>
<td>46.61 (12.70)</td>
</tr>
<tr>
<td>CDS</td>
<td>62.12 (9.63)</td>
<td>65.68 (12.87)</td>
</tr>
<tr>
<td>CDD</td>
<td>62.73 (12.34)</td>
<td>57.48 (16.21)</td>
</tr>
<tr>
<td>SRT</td>
<td>237.92 (22.08)</td>
<td>249.90 (28.94)</td>
</tr>
<tr>
<td><strong>MSI Group n = 22</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSP</td>
<td>42.38 (12.09)</td>
<td>40.42 (10.34)</td>
</tr>
<tr>
<td>CDS</td>
<td>63.92 (12.47)</td>
<td>64.95 (9.58)</td>
</tr>
<tr>
<td>CDD</td>
<td>65.59 (13.22)</td>
<td>62.60 (14.74)</td>
</tr>
<tr>
<td>SRT</td>
<td>232.54 (37.80)</td>
<td>249.18 (21.20)</td>
</tr>
</tbody>
</table>
Chapter Five
Discussion

The purpose of this study was to examine whether athletes exhibit any cognitive decline on neuropsychological testing subsequent to musculoskeletal injury. There was no known published research exploring the possible connection between acute musculoskeletal injury in sport and test scores of cognitive functioning at the time the current study was conducted.

Data analyses did not support the first three hypotheses. Hypothesis 1 stated that there would be significant decline in the MSI group at Time 2 compared to Time 1 for all subtests. Although mean scores for the injured group declined on the second assessment for MSP (H_{A1-a}) and CDD (H_{A1-c}), these changes were found to be nonsignificant by paired \( t \)-tests. This result suggests that the presence of musculoskeletal injury did not negatively influence cognitive performance within the injured group.

Hypothesis 2 stated that test scores of the MSI group would be significantly different from the comparison group at Time 2. ANOVA results showed no significant group effect on any of the subtests, nor were there any significant interactions of time and group for any of the subtests. Again, it appears the presence of musculoskeletal injury did not influence any significant changes in scores between the two groups.

Hypothesis 3 stated there would be no significant difference in test scores of the MSI group compared to the comparison group at Time 1. Again, ANOVA results showed no significant group effect for any of the subtests. This
result confirms that the comparison and injured groups are from the same population.

The inability to accept hypothesis 1 seems to indicate that injury in general has no effect on neurocognitive test scores. That is, musculoskeletal injury in this case did not influence the ability to perform on ANAM. This was supported by the ANOVA and paired $t$-test results. There were no significant group effects for any of the subtest scores, indicating that athlete performance on ANAM did not appear to be affected by injury. Similarly, ANOVA revealed that there was no interaction of time and group. Time did influence CDD ($H_{A1}$-c) and SRT ($H_{A1}$-d), as scores for the MSI group declined or improved, respectively, on the second assessment. Still, this change was consistent for both groups, meaning that both the injury and the comparison group performed worse on the second assessment of CDD, and improved on the second assessment of SRT.

Hypothesis 4, that there would be no significant differences in the comparison group at Time 2 compared to Time 1, was not accepted. ANOVA results indicated a significant main effect of time with CDD ($H_{A4}$-c) and SRT ($H_{A4}$-d). Follow-up paired samples $t$-tests revealed no significant differences for CDD at Time 2 compared to Time 1 with the comparison group. However, a paired samples $t$-test indicated SRT improved significantly at Time 2 in the comparison group.

A paired samples $t$-test was conducted on MSP ($H_{A4}$-a), showing a significant improvement in the comparison group at Time 2 compared to Time
1. After careful consideration, the inability to accept hypothesis 4-a needs to be examined further. This will be addressed following a brief recap and interpretation of results.

To begin, ANOVA results showed that time had a significant main effect on testing scores for CDD. Comparing the means, it was revealed that the comparison group performed worse on the second assessment (H₄-c); although a paired t-test revealed this to be non-significant. The MSI group scored worse on the second assessment as well (H₁-c), shown to be non-significant by a paired t-test. If the comparison group also had a decrease in performance, then it appears as these lowered scores cannot be attributed to the presence of musculoskeletal injury.

Interesting is the fact that healthy comparison group athletes performed more poorly on the second testing session, indicating that athletes in general had trouble at Time 2. This is important, as it could potentially impact the interpretation of poor CDD scores with concussed athletes. Specifically, if healthy comparison group athletes can be expected to perform poorly on a second assessment, then lowered performance within a concussed group might not actually be an indication of cognitive impairment at all.

Simple reaction time improved significantly for the comparison group (H₄-d), but it also improved significantly for the MSI group (H₁-d). Once again, the uniform change for both groups indicates that musculoskeletal injury did not influence test scores. This could potentially indicate that injury does not influence cognitive functioning as measured by simple reaction time or CDD, or,
it could simply mean that simple reaction time and CDD are not effective measures of post-injury cognitive functioning in athletes. MSP remained unchanged for the MSI group (H_A1-a), but significantly improved for the comparison group (H_A4-a). This is the only subtest where the two treatment groups differed significantly. It is unclear at this point why the two treatment groups would only differ on this assessment, and potential reasons for this will be discussed. Two points need to be made when interpreting this outcome.

First, the comparison group showed significant improvement on MSP Time 1 to Time 2. In the absence of any test aids, this would most likely be attributable to practice effects. Practice effects can be defined as the improvement on testing outcomes due to repetitive exposure to the same test (Lezak, Howieson, Loring, Hannay, & Fisher, 2004). In theory, ANAM is not easily susceptible to practice effects, as it allows for stimuli to be randomized across various testing sessions, resulting in alternate formats (Roebuck-Spencer, Sun, Cernich, Farmer, & Bleiberg, 2007).

There are types of tests, or characteristics of tests, that make them particularly vulnerable to practice effects. Lezak (1995) outlines some of these characteristics. These include tests that measure speed as a factor, tests that require a mode of response that is foreign or uncommon, tests that have an easily conceptualized single solution, or tests involving learning.

After subsequent testing it appears as though subjects learn how to set about and tackle the test more efficiently. "For many tests – particularly those with strong ceiling effects, such as digit span – the greatest practice effects are
likely to occur between the first and second examinations”, (Lezak et al., 2004, p.116).

MSP appears to fit many of those criteria. Once a subject has understood the idea of the test, the single solution can be easily conceptualized by those with good spatial processing skills. Subjects who do well will learn to look for characteristics of the sample that distinguish it from the incorrect answer.

The musculoskeletal group showed no significant improvement on the MSP subtest (H₁-a). Neither group was provided with any assistance during the lapse between the two tests; therefore, any improvement would be most likely due to the familiarity the subjects experienced from being exposed to ANAM (specifically the first assessment). To expand this idea further, ANOVA results demonstrated that there were no differences between the comparison and injured group at Time 1(H₃-a). Both groups were matched on the time lapse between their first and second assessment. The only notable difference at Time 2 was the experience of injury. This knowledge leads to the speculation that some aspect of injury prevented musculoskeletally injured athletes from improving on MSP subtest when their uninjured counterparts were able to improve. Cernich et al.(2007) state that the absence of practice effects is likely the indication of a concussion. Yet, as mentioned, these athletes were not concussed, rather musculoskeletally injured. It is unknown what specific feature of injury might be causing these attenuated practice effects, but likely one of the
three factors outlined in the review of literature (pain, physiological injury response, or pain) or a combination of any of them is at play.

Second, although MSP throughput scores did increase for the comparison group (Ha4-a), the other subtests did not exhibit this improvement. A possible explanation for this might be found in what the subtest is examining. Grindel, Lovell, & Collins (2001) found that speed of processing; memory and verbal learning are crucial in the evaluation of concussion, specifically the cognitive decline measurable by neuropsychological testing. MSP throughput scores are based upon performance on two of those tasks (speed of processing and memory). Therefore, it is logical that MSP scores might be sensitive to the presence of cognitive impairment following musculoskeletal injury as well. Further explanation for the detection of impairment in MSP and not in, let’s say SRT, might be explained by the cognitive demand of the tests. SRT has the least cognitive demand of the four subtests, and tests with higher cognitive demand might be more capable of discriminating between concussed and comparison participants (Bleiberg et al., 2004). Also, MSP had the strongest re-test reliability of the subtests measured in Cernich et al. (2007) that were used in this study. It is unknown what other factors may have influenced the same pattern in CDS and CDD. Possibly MSP is simply the most sensitive test to the presence of cognitive impairment. Spatial processing was shown to be sensitive to mTBI when compared to a comparison group, especially as the groups were tested over a period of four days (Cernich et al., 2007). Although the main cognitive function tested in MSP appears to be memory, there is also a spatial
processing component involved. The spatial processing subtest is not included in the current study due to the fact that some of the injured athletes’ baseline tests were given prior to it being included in the battery. It should be noted that the interpretation of the comparison group’s scores on MSP at this stage is purely speculation, especially given the fact that there was no interaction found in the ANOVA. Should the pattern of findings observed in this study of an improvement over time on MSP, identified only in the healthy athletes, be replicated, then it could be more clearly stated that MSI influences spatial processing and working memory (as measured by the ANAM-MSP subtest). More research is needed to further examine the sensitivity of specific subtests of ANAM to cognitive impairment. Some current literature uses sensitivity studies that are more than 10 years old (Cernich, 2007).

It is unclear what exact characteristic of musculoskeletal injury might be affecting performance on the ANAM-MSP subtest. Likely, some feature of the one of the three rationales listed in the literature review (pain, injury response, emotion), if not a combination of all three, is at play. Future studies into the impact of injury on neuropsychological testing should seek to include a reference for reporting pain being experienced by athletes at the time of assessment. Athletes could rate their pain on a scale, comparing it to pain at the time of injury. Similarly, in this study injuries were not graded on their severity. Prospective studies could allow for the injuries sustained by participants to be graded to determine whether severity of the injury, and consequently severity of the physiological injury response, affects testing
scores. Finally, athletes could fill out an emotional grading survey, like the Profile of Mood States (POMS) questionnaire, to determine if particular emotions are present at the time of assessment.

The current study stratified the subjects on time and gender, but there was no matching of sports. It is unclear if certain aspects of particular sports have any impact on testing scores.

Histories of previous concussions were collected on the athletes. All athletes were clear of any concussive symptoms when completing NP testing, but they were still asked to report the number of previously sustain concussions. It had no impact on their inclusion in the study. It is unknown whether history of previous concussions had any effect on their ANAM performance, as this was not assessed in this study.

As mentioned, practice effects were presumed to be the cause of the improvement seen in the comparison group. MacIntire and Miller (2007) state that long intervals between testing sessions may reduce practice effects. Future studies might aim to take only athletes who amassed a considerable lapse of time (e.g.; 1 year or more) between baseline and injury to try an eliminate practice effects. If the current findings hold true, then with the absence of practice effects, results should reflect no difference in the comparison group at both time points, and degradation of test scores in the injury group at Time 2 on the subtests where the comparison group showed improvement (CDS, CDD, SRT). Though this study matched subjects on time lapse, some of these lapses were only of several days, where practice effects might be strong in the
comparison group and injury effects may still be lingering in the experimental group.

Finally, a greater sample size could help reduce variability and strengthen the power of the analysis. A greater sample size would help show whether other subtests begin to show a trend of practice effects for the comparison group, and the absence of practice effects for the injured group. In this study, power calculations for an 80% probability of correctly rejecting the null hypothesis indicated an $N$ of 30 would have been sufficient to satisfy the requirements for all subtests (MSP = 18, CDS = 27, CDD = 24, SRT = 30). This study originally recruited 23 (before exclusion) which was sufficient to satisfy a 70% probability of correctly rejecting the null hypothesis (MSP = 14, CDS = 20, CDD = 18, SRT = 23).

Conclusion

The current study sought to determine whether athletes demonstrate any cognitive dysfunction following MSI. Analyses did not indicate that MSI significantly impaired cognition as measured by ASMB testing. Analyses did suggest, however, that athletes with musculoskeletal injuries did not demonstrate the practice effects observed in the comparison group on a particular subtest (MSP).

It is unknown what aspects of MSP proved to be difficult for injured athletes on the second assessment. Similarly, it is unknown what aspects of MSI itself impaired improvement.
The results of this study are important because they indicate that athletes with musculoskeletal injuries do not show cognitive improvement (i.e. practice effects) as measured by a test of working memory. Previously, cognitive assessment post-MSI has not been done, because it has not been considered relevant. Given the reported results, this practice, or the lack thereof, should potentially be reconsidered.

In summary, this study has shown that there does not appear to be significant negative cognitive impact from MSI, as measured by ASMB. Findings do suggest, however, that the presence of musculoskeletal injury influences spatial processing and working memory (as measured by MSP) to the extent that practice effects typically seen are absent. These results indicate that more research is needed to further delineate cognitive functioning post-MSI.
References


APPENDIX A

(Demographics Form)
Instructions: Please complete the following information as best you can. The information that you provide will be kept strictly confidential. Only the investigators will have access to the information. If you have questions about a particular question, leave it blank and ask the researcher for clarification. Thank you very much for your cooperation.

NAME: ____________________________________________________________

1. What is your sex?   1.   M A L E       2.   F E M A L E

2. What is your date of birth? (mm/dd/yyyy)   _________ / _________ / _________

3. What is your height? _______________ (Feet) or _____________ (cm)

4. What is your weight? _______________(Lbs.) or ______________(kg)

5. Do you consider yourself to be: 1. LEFT HANDED   2. RIGHT HANDED   3. BOTH

6. To what ethnoracial group do you belong?

   i.   CAUCASIAN (WHITE)   v.   HISPANIC
   ii.  AFRICAN ORIGIN (BLACK)   vi.  EAST INDIAN
   iii. ASIAN   vii.  WEST INDIAN
   iv.  SOUTH ASIAN   viii. OTHER/MIXED ____________ (SPECIFY)

7. What is the highest level of education completed by your father and mother?

   FATHER
   i.   SOME HIGH SCHOOL OR LESS
   ii.  HIGH SCHOOL GRADUATE
   iii. POST-SECONDARY VOCATIONAL TRAINING
   iv.  COLLEGE GRADUATE
   v.    SOME UNIVERSITY
   vi.  UNIVERSITY GRADUATE (e.g., BSc)
   vii.  MASTERS DEGREE (e.g., MSc)
   viii.  DOCTORAL DEGREE (e.g., PhD)
   ix.   PROFESSIONAL DEGREES (e.g., DOCTOR, LAWYER)

   MOTHER
   i.   SOME HIGH SCHOOL OR LESS
   ii.  HIGH SCHOOL GRADUATE
   iii. POST-SECONDARY VOCATIONAL TRAINING
   iv.  COLLEGE GRADUATE
   v.    SOME UNIVERSITY
   vi.  UNIVERSITY GRADUATE (e.g., BSc)
   vii.  MASTERS DEGREE (e.g., MSc)
   viii.  DOCTORAL DEGREE (e.g., PhD)
   ix.   PROFESSIONAL DEGREES (e.g., DOCTOR, LAWYER)
8. What varsity team do you play for (e.g. Men's hockey / Women's soccer)?

9. How many years have you played with this team (before this year)?

10. What position do you play?

11. What academic program are you registered in at U of T?

12. Is English your first language? 1. YES 2. NO
   If No, at which age did you begin to acquire the English language?

For the purpose of the next few questions, an injury is defined as any physical harm resulting in pain or discomfort that causes one or more of the following:

a. Unable to participate in sport activity during one or more practices, training sessions, or competitions
b. A need to modify physical activities during practice, training, or competition.
   c. Sufficient distraction or emotional distress to interfere with concentration or focus during one or more practices, training sessions, or competitions.

13. Are you currently injured? 1. YES 2. NO

14. Please circle the numbers below that indicate the location of any current injuries.

<table>
<thead>
<tr>
<th>Injury #1</th>
<th>Injury #2</th>
<th>Injury #3</th>
<th>Injury #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Right</td>
<td>Right</td>
<td>Right</td>
</tr>
<tr>
<td>Left</td>
<td>Left</td>
<td>Left</td>
<td>Left</td>
</tr>
<tr>
<td>Both</td>
<td>Both</td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td>Head</td>
<td>Head</td>
<td>Head</td>
<td>Head</td>
</tr>
<tr>
<td>Neck</td>
<td>Neck</td>
<td>Neck</td>
<td>Neck</td>
</tr>
<tr>
<td>Shoulder, armpit</td>
<td>Shoulder, armpit</td>
<td>Shoulder, armpit</td>
<td>Shoulder, armpit</td>
</tr>
<tr>
<td>Upper arm, elbow</td>
<td>Upper arm, elbow</td>
<td>Upper arm, elbow</td>
<td>Upper arm, elbow</td>
</tr>
<tr>
<td>Lower arm, wrist</td>
<td>Lower arm, wrist</td>
<td>Lower arm, wrist</td>
<td>Lower arm, wrist</td>
</tr>
<tr>
<td>Hand, fingers</td>
<td>Hand, fingers</td>
<td>Hand, fingers</td>
<td>Hand, fingers</td>
</tr>
<tr>
<td>Upper back, rib cage</td>
<td>Upper back, rib cage</td>
<td>Upper back, rib cage</td>
<td>Upper back, rib cage</td>
</tr>
<tr>
<td>Low back, pelvis, abdomen</td>
<td>Low back, pelvis, abdomen</td>
<td>Low back, pelvis, abdomen</td>
<td>Low back, pelvis, abdomen</td>
</tr>
<tr>
<td>Knee</td>
<td>Knee</td>
<td>Knee</td>
<td>Knee</td>
</tr>
<tr>
<td>Hip, thigh / upper leg, knee</td>
<td>Hip, thigh / upper leg, knee</td>
<td>Hip, thigh / upper leg, knee</td>
<td>Hip, thigh / upper leg, knee</td>
</tr>
<tr>
<td>Lower leg, ankle</td>
<td>Lower leg, ankle</td>
<td>Lower leg, ankle</td>
<td>Lower leg, ankle</td>
</tr>
<tr>
<td>Foot, toe</td>
<td>Foot, toe</td>
<td>Foot, toe</td>
<td>Foot, toe</td>
</tr>
</tbody>
</table>

15. Are you receiving any treatment for the injury at present? 1. YES 2. NO
   If "YES", please describe briefly:
16. Have you ever had an injury to the head (e.g. from a collision, a fall, a punch, a car accident) that resulted in any of the symptoms in the table below? If so, for each injury, indicate the date and the associated symptoms.

<table>
<thead>
<tr>
<th>1st injury</th>
<th>2nd injury</th>
<th>3rd injury</th>
<th>4th injury</th>
<th>5th injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of Injury (month / year)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Momentary disorientation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Memory problems:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headache</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nausea or vomiting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blurred vision or &quot;seeing stars&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skull fracture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brief loss of consciousness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prolonged loss of consciousness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep disturbance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mood changes (e.g. irritability, sadness, other):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other symptoms</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specify _____________</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

17. Are the symptoms of the most recent head injury still present or completely cleared?
   1. STILL PRESENT
   2. COMPLETELY CLEARED

18. Please list ALL medications, pills, drugs, vitamins/supplements that you are now taking:
APPENDIX B

(Consent Form)
Title of research project:
“Empirically Validated Return-to-Play Guidelines for Sport-Related Concussion”

Investigators:
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Robin Green, Ph.D.
Paul Comper, Ph.D.
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Michael Hutchinson, B.Sc., phone: (416) 978-5307
Richard Wennberg, M.D., F.R.C.P.(C)
Sam Slobounov, Ph.D.
Sean Bisshop, M.A.

Sponsor/Funding:
Physicians’ Services Incorporated (PSI), 5160 Yonge St. Toronto, On., M2N 6L9
phone: (416) 226-6323, fax: (416) 226-6080
PSI Grant # 04-50

Background & Purpose of Research:
The primary purpose of the study is to validate empirically a set (or sets) of return to play guidelines. This will allow for the valid and reliable assessment of an athlete’s “readiness” for return-to-play following MTBI; readiness refers to an athlete’s ability to function in an athletic environment in which the optimal functioning of both cognitive and motor/vestibular functioning are needed for safety and for competitive performance.

Approximately 600 student athletes from the University of Toronto and the Pennsylvania State University will participate in the baseline testing protocols. We anticipate approximately 60 athletes will participate in post concussion testing.

This study is being undertaken so that, using the combination of cognitive and neurophysiological serial testing as the gold standard for identification of symptom resolution, each of 4 existing sets of return-to-play guidelines will be assessed for their respective ability to accurately predict symptom resolution, and therefore the safe and un-prolonged return to play.

Eligibility:
To participate in this study you must be participating in sports at the university level that are considered to be high risk for concussion (eg. Football, hockey, lacrosse, rugby, soccer). Both male and female athletes are invited to participate in all aspects of this study.

Procedures:
Neuropsychological Testing:
Upon arrival at the lab you will be seated and asked to fill out background demographic information sheets and injury history forms. Following this the tester will explain the testing procedures for the neuropsychological testing session. The tests are administered as standard paper and pencil tests for which you are seated at a table and administered the test battery by the tester. You will be instructed to complete the tests as quickly and accurately as possible. The test battery assess several domains of functioning: (1) learning and memory (2) attention and concentration (3) speed of processing (4) executive functioning and strategy application (5) language skills and (6) premorbid intellectual functioning. Psychosocial and personality measures were included in the assessment in order to assess transient moods, perceived stress, and perfectionism.

Next, you will be asked to complete the computerized test battery. This is the Automated Neuropsychological Assessment Metrics (ANAM). It consists of numerous subtests that assess speed of information processing and specific subcomponents of attention. ANAM is a self-directed computerized neuropsychological battery that will take you approximately 25 minutes to complete. The entire neuropsychological test battery takes 45 minutes to complete.

Neurophysiological Testing:
Upon arrival at the lab you will be asked to sit in a chair as the EEG electrodes are applied. Your scalp will be cleaned with rubbing alcohol; this is done to remove any oil and dirt residue on the scalp. An elastic cap containing 21 evenly spaced sensors will then be placed on the head. The cap completely covers the scalp and the sensors are found from the back of the scalp to the forehead, and from ear to ear. A blunt-ended syringe (absolutely no injections are made) will then be filled with gel. The syringe is used to place the gel between the sensors on the cap and the scalp; this will help ensure the researchers collect brain electrical activity that has no interference from the outside environment. Standard EEG recordings will be taken under the following conditions: eyes open and eyes closed standing under normal, everyday postural movements, eyes open and eyes closed seated and under a cognitive math task, and eyes open and eyes closed seated event-related potentials (ERPs), where an auditory sound is heard through headphones during standard EEG recording. The EEG is recorded using the Mitsar EEG recording equipment. The EEG recordings will not be linked to any of the other recording equipment.

Postural stability is assessed using the Balance Error Scoring System (BESS). The BESS consists of 3 postures held for 20 seconds each and each posture is performed twice (total of 6 postures held for 20 seconds each). The postures are: (1) two-footed stance with feet together and eyes closed, (2) one-footed stance on non-dominant foot with eyes closed, and (3) tandem stance with non-dominant foot forward. Each time you deviate from the specified posture within the test period 1 point will be marked. The total points for all postures will be added together to calculate a total score for postural stability.

Voluntary Participation & Early Withdrawal:
Your participation in this study is voluntary and you may withdraw from this study at any time by notifying the investigator. Your withdrawal from this study or your refusal to participate in no way affects your care or access to medical services and in no way will affect your academic career.

Risks/Benefits:
Benefits: You will be provided with neuropsychological and neurophysiological information about the persistence/resolution of your concussion symptoms or emotional symptoms related to your injury. Additionally, a more accurate diagnosis of my injury will be made and safer and more accurate decisions as to when it is appropriate to return to competition can be made using the proposed examination techniques than by conventional measurement tools.
Risks: The risks to participating in this study are minimal. However, there is a chance of dizziness, especially post concussion. Spotters will be used to aid you if you feel dizzy or begin to fall. The experiment will be terminated immediately at your request.

Privacy & Confidentiality:
Your medical files in the MacIntosh Clinic at the University of Toronto are kept private and confidential in keeping with the laws of Ontario (the Medicine Act, and the Regulated Health Professions Act). They will be used by health professionals at the MacIntosh Clinic in the normal ways for your clinical care, whether you consent to participate in this study or not. Your medical data will not be released to the investigators in this study for research purposes unless you consent to participate in this study. In that event, the relevant medical records only (those pertaining to concussion or other minor injury used as a control case in this study) will be made anonymous by stripping your name and all other identifying features from them save a numeric subject code that will be kept confidential.
Only the Investigators listed below will have any access to your data collected by neuropsychological or neurophysiological (EEG or balance tests) testing (except for Dr. Doug Richards, who will remain blinded to these data). Following the initial intake, these records of neuropsychological and neurophysiological test data are also made anonymous by the use of a confidential numeric subject codes as the only identifier on them.
Data are stored securely stored in a locked room with limited access (accessible only to investigators) and within this room they are stored in locked cabinets. Data are kept for a period of 10 years. In the event that you withdraw from the study, any data collected up to that point will be kept for a period of 10 years.
Please note that confidentiality can only be guaranteed to the extent permitted by law.

Publication of research findings:
Following the conclusion of this study the results may be published. No information that could reveal you as a participant will be disclosed in any subsequent publication.

New Findings:
If anything comes to light during the course of this research which may influence your decision to continue, you will be notified.

Compensation:
Financial compensation of $20 (Cdn) will be given to you if you participate in the one-time EEG and balance portions of the study. This amount is proportional to the amount of time and effort required by you during the 1-hour testing. This is justifiable since EEG and balance testing are still considered to be experimental techniques for the assessment of concussion whilst neuropsychological testing is considered to be the current ‘gold-standard’ being used for concussion assessment and is part of your mandatory baseline medical assessment.
Additionally, $10 (Cdn) per EEG and balance testing session will be given to you if you sustain a concussion and voluntarily undertake follow-up testing. There will be a maximum of two follow-up EEG and balance testing sessions after injury, therefore, a maximum post-injury total compensation of $20 Cdn.

Rights of Subjects:
You waive no legal rights by participating in this trial.
If you have any questions regarding your rights as a participant you may contact the Ethics Review Office for University of Toronto Health Sciences at Simcoe Hall, 27 King's College Circle, Room 10A, Toronto, Ontario, M5S 1A1, telephone (416) 946-5763.

Dissemination of findings:
As a research participant you have the right to request a copy of the final report of the findings of this research study.

Copy of informed consent for participant:
You are being given a copy of this informed consent to keep for your own records.

Consent to Participate:

Name: ____________________________

By signing in any of the spaces below, I acknowledge that any questions that I had have been addressed adequately by the investigators or the information sheet, which I have read and which I understand. I acknowledge that I may withdraw from the study at any time and without penalty. I understand that if I have any questions I may contact the investigators or their assistants, Michael Hutchison or James Thompson at 416-978-5307.

A. I hereby consent to participate in both the neuropsychological and neurophysiological components of the study at this time:

Signature: ____________________________

Date: ________________

Or

B. I hereby consent to participate in only the neuropsychological component of the study at this time:

Signature: ____________________________

Date: ________________

Or

C. I do not consent to participate in any part of the study at this time. However, during the season, if I sustain a concussion or minor injury, I give my permission for the sport medicine personnel at the University of Toronto to report the injury to the Concussion Program Research Team, and for the research team to contact me then to ask if I would like to participate in the research and post-injury testing at that time.

Signature: ____________________________

Date: ________________
Witness: _________________________________
Signature: _________________________________   Date: _________________

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Assistant Professor
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APPENDIX C

(Power Calculations)
ANAM scores from injured athletes were needed to calculate the sample size required. Since the current study was novel with athletes with acute MSI injuries were being testing, there was no existing data from which to draw on for the statistical calculation. Therefore, research with data on scores obtained from ANAM testing following mTBI was used. Studies by McCaffrey et al. (2007) and Daniel et al. (1999) on concussed football players were used to provide average values for one of the samples. Existing clinical data on ANAM norms was used for a second sample. ANAM subtest means and standard deviations are provided in Table 4 below.

\[
\text{Sample size} = n = \left( \frac{z\sigma}{d} \right)^2
\]

Table 4 Subtest means (standard deviations) for power calculations

<table>
<thead>
<tr>
<th>SUBTEST</th>
<th>SAMPLE 1</th>
<th>SAMPLE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSP</td>
<td>49.47(13.86)</td>
<td>39.30 (10.422)</td>
</tr>
<tr>
<td>CDS</td>
<td>53.78(8.42)</td>
<td>60.02 (9.885)</td>
</tr>
<tr>
<td>CDD</td>
<td>50.28(14.23)</td>
<td>60.05 (12.726)</td>
</tr>
<tr>
<td>SRT</td>
<td>254.46(28.66)</td>
<td>236.9 (25.714)</td>
</tr>
</tbody>
</table>
APPENDIX D

(ANOVA and Paired Samples t-Tests Summary)
Table 4 – Summary of ANOVA

<table>
<thead>
<tr>
<th>Subtest</th>
<th>Within-Subjects (Time Effect)</th>
<th>Between-Subjects (Group Effect)</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSP</td>
<td>$F(2, 42) = .674, p = .416$</td>
<td>$F(2, 42) = .679, p = .414$</td>
<td>$F(2, 42) = 4.016, p = .052$</td>
</tr>
<tr>
<td>CDS</td>
<td>$F(2, 42) = 2.848, p = .099$</td>
<td>$F(2, 42) = .029, p = .865$</td>
<td>$F(2, 42) = .870, p = .356$</td>
</tr>
<tr>
<td>CDD</td>
<td>$F(2, 42) = 4.164, p = .048^*$</td>
<td>$F(2, 42) = 1.119, p = .296$</td>
<td>$F(2, 42) = .315, p = .577$</td>
</tr>
<tr>
<td>SRT</td>
<td>$F(2, 42) = 9.654, p = .003^*$</td>
<td>$F(2, 42) = .180, p = .673$</td>
<td>$F(2, 42) = .256, p = .615$</td>
</tr>
</tbody>
</table>

“*” denotes a significant result.

Table 5 – Summary of Paired Samples $t$-Tests

<table>
<thead>
<tr>
<th>Subtest</th>
<th>Comparison Group</th>
<th>MSI Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSP</td>
<td>$t(21) = -2.529, p = .020^*$</td>
<td>$t(21) = .713, p = .484$</td>
</tr>
<tr>
<td>CDS</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>CDD</td>
<td>$t(21) = 1.589, p = .127$</td>
<td>$t(21) = 1.288, p = .212$</td>
</tr>
<tr>
<td>SRT</td>
<td>$t(21) = -2.308, p = .031^*$</td>
<td>$t(21) = -2.187, p = .040^*$</td>
</tr>
</tbody>
</table>

“*” denotes a significant result.