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Factors Predicting Return to Play in Sports-Related Concussion: An Empirical Evaluation

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FACTORS PREDICTING RETURN TO PLAY IN SPORTS-RELATED CONCUSSION:

AN EMPIRICAL EVALUATION

By

Douglas R. Polster, M.S.

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DISSERTATION APPROVAL SHEET

This dissertation was submitted by Douglas R. Polster under the direction of the Chairperson of the dissertation committed listed below. It was submitted to the School of Psychology and approved in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Clinical Psychology at Nova Southeastern University.

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NOTE: Information in this copy is redacted due to pending business contract

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FACTORS PREDICTING RETURN TO PLAY IN SPORTS-RELATED CONCUSSION: AN EMPIRICAL EVALUATION

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ABSTRACT

Sports-related concussion and its subsequent management have become a top priority within the sports medicine research spectrum. In order to properly understand the complex nature of concussion management, multiple aspects of the injury were explored including the psychobiological nature of the injury, risk for further injury, diagnostic concerns, and return to play decision making. While much research has been dedicated to these areas, one in particular, return to play, is the focus of this current research study. To date, there has not been a method for accurately predicting return to play time after an athlete has sustained sports-related concussion. In order to advance the understanding of return to play and the clinical management of concussion, the current study applied a unique statistical methodology to empirically develop an equation to predict average return to play time using a set of post-injury variables. This equation predicted average return to play time with significant accuracy and resulted in a strong correlation between predicted return to play time and observed return to play time. Importantly, the predication equation was moderately stable across multiple samples. The results suggest that return to play time can be successfully predicted via a set of post-injury variables. Thus, the understanding of concussion severity as well as the clinical management of the injury can be

improved by providing clinicians with a better estimate of the length of time an athlete will be unable to participate in a given activity before full recovery.

CHAPTER I

Statement of the Problem

Debate concerning sports-related concussion has peaked recently, as the sports world familiarizes itself with an injury that has historically been difficult to define. Within the past fifteen years alone, four international symposiums on concussion in sport have been convened to discuss everything from defining concussion to the implementation of appropriate diagnostic strategies and return to play protocols (Aubry et al., 2002; McCrory et al., 2005; McCrory, et al., 2009; McCrory et al., 2013). The increased awareness of sports-related concussion has resulted in an onslaught of research devoted to further understanding the injury. Among other things, the empirical investigation of concussion has demonstrated that while most athletes recover within 7-10 days (McCrory et al., 2013), the injury is much more serious than believed 20-30 years ago. A combination of psychobiological abnormalities, idiosyncratic symptom presentations, and difficulties in diagnosis have led researchers and clinicians (e.g., medical doctors, psychologists, athletic trainers, etc.) to alter their management of the injury and create new protocols to keep athletes from all competitive levels safe. While the past twenty years have seen an exponential increase in the concussion literature, many aspects of the injury remain in need of further investigation, including definitive diagnostic procedures, evidenced-based treatment approaches, and the universal implementation of standardized return to play (RTP) management protocols.

An area in which concussion research has truly advanced the understanding of brain injuries is in the psychobiological aspects of the injury. Past research on brain injury had focused primarily on more severe forms of traumatic brain injury (TBI) while neglecting mild TBI, which is historically referred to as concussion. Due to the increase in empirical investigation of concussion, it has been categorized as a functional, rather than a structural injury (Giza & Hovda, 2001; Giza & Hovda, 2014). That is, the injury results in problems associated with brain functions that are metabolic in nature and mostly characterized by neuronal dysfunction. Once an athlete sustains a concussion, the brain experiences an “energy crisis,” which is a term coined by Giza and Hovda in 2001 that refers to the altered glucose metabolism, reduced cerebral blood flow, and axonal dysfunction that underlies changes in neurotransmission (Giza & Hovda, 2001). This energy crisis is suspected of causing symptoms such as poor attention, memory problems, and affective disturbances (Giza & Hovda, 2014).

Historically, clinicians were bound by the generic recommendations of concussion grading systems, which extrapolated the level of metabolic dysfunction from a combination of the athletes’ self-report and an approximation of either their amnestic periods or the length of time that they were left unconscious as a result of the injury (Cantu, 2001). In response to the continued reliance of subjective athlete reports that dominate the clinical management of concussion, researchers and clinicians have systematically attempted to establish novel diagnostic methods. Although concussion grading systems are no longer widely used, athlete self-reports remain a critical part of the assessment process for concussion-related injuries. Empirical studies have documented the tendency for athletes to under-report their subjective symptoms of concussion and have demonstrated the effectiveness of neuropsychological evaluation as an objective measure for concussion evaluation (McCrory et al., 2013). The use of neuropsychological testing has also demonstrated that while an athlete may no longer experience subjective symptoms, he or she may still demonstrate brain dysfunction.

One of the most widely used neuropsychological screening tests for concussion is the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) instrument, which assesses an athlete’s memory, processing speed, and reaction time, as well as their subjective level of concussion-related symptoms (Lovell, Collins, & Bradley, 2004a). RTP decisions are currently based on the combination of a “normal” neurocognitive performance and the establishment of an asymptomatic status. Given the importance of neurocognitive performance and the presence (or absence) of concussion symptoms in the RTP process, understanding the relationship between these constructs as well as their influence on RTP times is essential. Thus, it is critical to explore and evaluate predictors of concussion severity as they relate to RTP time. While a significant amount of research has been dedicated to exploring predictors of concussion severity, no research exists that attempts to formulate a prediction model of concussion severity based on these constructs. Since a safe, quick RTP is critical for athletes, it is imperative that research explores the predictability, in days, of an athlete’s time out of play that is based on empirically-derived factors. Research up to this point has concentrated on unique, individual predictors of severity, but a next logical step is to assess the cumulative predictability of multiple factors related to concussion severity. Therefore, this study will examine factors related to concussion using a novel statistical approach and will seek to establish the predictability of RTP time, in days, based on numerous factors associated with concussion symptoms and neurocognitive performance.

CHAPTER II

Review of the Literature

Over the past 50 years, the conceptualization of concussion has evolved dramatically, reflecting the great deal of research examining the mechanism, presentation, and prognosis of the injury. As such, it is important to understand the various aspects of the injury. The following literature review will expand upon the psychobiological aspects of the injury, diagnostic concerns, diagnostic guidelines, return to play decision making, and prognostic indicators as a way to provide information on how past and current research has led to the current conceptualization of the injury.

Defining Concussion

Concussion has historically been considered a mild traumatic brain injury (mTBI). Past definitions have included loss of consciousness (LOC) as a prerequisite for the injury; however, based on data presented at the initial world-wide conference on concussion in sport, LOC is no longer considered a requirement for the injury. As such, the following definition has been adopted by the International Conference on Concussion in Sports:

> Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features that incorporate clinical, pathologic and biomechanical injury constructs that may be utilized in defining the nature of a concussive head injury include:
>
> 1. Concussion may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head.
>
> 2. Concussion typically results in the rapid onset of short-lived impairment of neurologic function that resolves spontaneously. However, in some cases, symptoms

> and signs may evolve over a number of minutes to hours.
>
> 3. Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies.
>
> 4. Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course. However, it is important to note that, in a small percentage of cases, symptoms may be prolonged. (McCrory et al., 2013, pp. 250-251)

Given the comprehensive definition of concussion, it is important for those in the field to understand how all of the pieces fit together. In order to properly understand the complex nature of concussion, a variety of aspects will be reviewed including the psychobiological basis of the injury, diagnostic concerns, diagnostic guidelines, and the current state of RTP guidelines. In addition to current diagnostic guidelines, predictors of concussion severity will also be reviewed.

Psychobiological Nature of Concussion

In the past 20 years, clinical presentations of concussion have been extensively studied. However, while the clinical presentation is important, it is imperative that clinicians understand how the brain is affected by the injury in order to fully comprehend the risks involved in allowing an athlete to return to play too soon. Psychobiological research into the nature of the injury has augmented the existing qualitative clinical data provided by studies of injured athletes (e.g., Katayama, Becker, Tamura, & Hovda, 1990; Barkhoudarian, Hovda, & Giza, 2011). Animal models for concussion have been established to help researchers and clinicians understand the neuro-mechanical processes after the brain has sustained a mild injury (i.e., concussion; Giza & Hovda, 2001; Giza & Hovda, 2014). This was an early goal of researchers in the field to determine the true nature of the injury, and as the majority of research now suggests, there is a difference between concussion-related injuries and the neuro-biological processes that occur following moderate to severe TBI. Thus, it is critical to highlight some of the major differences between these two kinds of brain injuries (i.e., mild and moderate-to-severe). Next, it is important to explore the role of the “energy crisis” (as described by Giza & Hovda, 2001) and the ensuing axonal damage that occurs during concussive injuries. Finally, the risk of repeated injury will be discussed.

Energy crisis. One of the major differences found between a concussion and more severe TBI is the qualitative nature of the neuronal injury. For decades, it was believed that the brain was not permanently injured after a person sustained a concussion. Unlike in TBI, where the injury results in neuronal death and can be objectively observed through a variety of neuroimaging approaches (i.e., Computerized Tomography, Magnetic Resonance Imaging), the concussive injury was understood to involve neuronal dysfunction, often in the absence of positive findings on traditional neuroimaging studies (Giza & Hovda, 2001; Giza & Hovda, 2014). Since cell death was not believed to occur in concussion, the injury was conceptualized as almost exclusively metabolic in nature. The resulting biological aspects of the injury were therefore described as a “metabolic cascade” which is represented by the “energy crisis” in the brain as described by Giza and Hovda (2001, p. 228). Although recent research on Chronic Traumatic Encephalopathy (CTE) has shown that cell damage does, indeed, occur with both concussive and sub-concussive blows to the head, the groundbreaking research into the metabolic aspects of concussion helped to create a biological framework for researchers to explore the biological sequelae of concussive injuries.

Katayama et al. (1990) first examined the influx of ions in extracellular space following concussion. They identified massive potassium (K+) flux in the hippocampus immediately after a biomechanical injury to the brain. The increase in K+ in concussion was significant enough to cause an indiscriminant release of excitatory amino acids (EAAs; Katayama et al., 1990) and it was determined that the most highly concentrated EAA following brain injury was glutamate. This study helped to form the foundation that concussion is a functional rather than a structural injury when compared to TBI. Due to the increase in extracellular K^+ following a concussion, the sodium-potassium pump must work at an increased rate in order to restore the cell to its resting state. After the injury, the sodium-potassium pump works harder than usual and hence quickly reduces the energy supply of the cell, requiring the cell to rely on glycolysis (a metabolic process which breaks down glucose and glycogen, forming lactic or pyruvic acid for energy; Glycolysis, 2014; Barkhoudarian et al., 2011). Previous research has demonstrated that an initial increase in glucose metabolism occurs immediately after injury, followed by a sudden decrease (Yoshino, Hovda, Kawamata, Katayama, & Becker, 1991). This sudden decrease in glucose metabolism leaves the brain “starved” for energy and unable to adequately heal itself in a timely fashion.

Contributing to the energy crisis is the increase in concentration of calcium (Ca^{2+}) in the mitochondria. Xiong, Gu, Peterson, Muizelaar, and Lee (1997) examined the effect of increased Ca^{2+} in forebrain mitochondria of injured rats. The increase in Ca^{2+} was associated with a decrease in energy efficiency and glucose oxidation dysfunction. Given that the mitochondria studied were extracted from the forebrain, it is possible that the decrease in energy efficiency that occurs in the forebrain may be associated with “fogginess” which is a symptom commonly reported by athletes suffering from concussion (Giza & Hovda, 2001).

Related to hypoglycolysis is the effect of the injury on cerebral blood volume (CBV). Immonen et al. (2010) studied the effect of TBI on CBV in rats. Rats received controlled cortical impact injuries and three regions (primary lesion, perilesional area, and hippocampus) were examined. While all regions eventually recovered, areas such as the hippocampus took up to two weeks to recover normal levels of CBV (Immonen et al., 2010). The decrease in CBV is likely to contribute to the energy crisis as well, given that glucose availability is decreased as CBV is decreased. Therefore, after the initial spike, hypoglycolysis may be exacerbated by a decrease in CBV as the cell struggles to find the energy sources it needs. Given that decreases in CBV are seen up to two weeks post-injury, it is possible that difficulties with memory and “fogginess” are a result of hippocampal dysfunction. In addition, it has been shown that cognitive exertion can increase symptom presentation in concussed athletes (Giza & Hovda, 2001). As such, it appears that the energy crisis is a main contributor to subjective symptom presentation.

Axonal damage and dysfunction. Axonal damage has also been associated with concussion. Unlike severe TBI, where the damage is usually permanent, the axonal damage in concussive injuries usually refers to the stretching, but not tearing, of axons. Spain et al. (2010) investigated myelin integrity and axonal damage in mice after mild lateral fluid percussion injury. Myelin integrity was minimally affected by the injury whereas axonal damage (i.e., stretching) was found at multiple time points post-injury (Spain et al., 2010). Damage to axons in visual-spacial tracts may affect the transfer of visual and spatial information as it relates to body movement based on the connection to the superior parietal lobe and the hippocampus. In addition, axonal damage was found in the dorsal thalamic nuclei at six weeks post-injury (Spain et al., 2010). A disruption in the tracts bringing information to and from the dorsal thalamic nuclei may result in problems with active memory. If this information is to be extrapolated to humans, it may be understood that concussed individuals would report having difficulty with memory or learning immediately after sustaining an injury.

Risk of Further Injury Following Concussion

Second Impact Syndrome. Another major issue in concussion is the risk of developing Second Impact Syndrome (SIS) following repeated brain injury. SIS occurs when "an athlete who has sustained an initial head injury, most often a concussion, sustains a second head injury before symptoms associated with the first have fully cleared" (Cantu & Voy, p. 27, 1995). The athlete usually displays concussion symptoms after the first hit (headache, fogginess, difficulty concentration, etc.). In SIS, after a second hit (which may be minor in nature), within seconds to minutes the athlete falls to the ground, his or her pupils rapidly dilate, and breathing stops. SIS often results in death or a vegetative state after a process in which brain swelling/dysautoregulation (e.g., increased intracranial pressure) results in subdural hematoma (Wetjet, Pichelmann, & Atkinson, 2010; Cantu & Gean, 2010). The first cases of SIS were detailed by Schneider (1973) when two athletes died after sustaining concussions and subsequent second hits to the head (Wetjet et al., 2010). While the prevalence of SIS has been hard to estimate, Boden, Tacchetti, Cantu, Knowles, and Mueller (2007) examined injury data from 1989 to 2002 and discovered 94 cases of catastrophic brain injury (8 deaths, 46 permanent neurological damage, 36 serious with full recovery) in high school and college football players, which the authors concluded reflects an estimate of less than 1 per 100,000.

Early investigations into SIS questioned the validity of the SIS diagnosis. McCrory and Berkovic (1995) performed a literature search to review possible cases of SIS. Their search included all published cases of catastrophic brain injury or SIS in sport that had at least one of the following criteria: a) medical review after a witnessed first impact; b) documentation of ongoing symptoms following the initial impact up to the time of the second impact; c) witnessed second head impact with subsequent rapid cerebral deterioration; and d) neuropathologic or neuroimaging evidence of cerebral swelling without significant intracranial hematoma or other cause for cerebral edema (e.g., encephalitis). According to those criteria, the authors identified the following

- Definite SIS criteria: a), b), c), and d)
- Probable SIS criteria: c) and d) plus either a) or b)
- Possible SIS criteria: c) and d) only
- Not SIS criteria: c) or d) absent

(McCrory & Berkovic, p. 678, 1995)

Of the 17 published studies identifying SIS as the cause of the brain injury, using the criteria listed above, there were no cases of definite SIS, five cases of probable SIS, and 12 cases that were not SIS. Most of the SIS cases were males between the ages of 16-24 (McCrory & Berkovic, 1995). While the authors did not find any cases of definite SIS, it is important to note that lacking criteria a) or b) does not imply an athlete did not sustain a first hit or suffer from ongoing symptoms.

While the diagnostic label of SIS is still controversial, there seems to be a link between symptoms lingering from a first hit and catastrophic brain damage from a second hit. Cantu and Gean (2010) examined history and CT findings in 10 cases of SIS involving athletes from age 10-19. In each case, the athlete suffered LOC in the first injury and LOC with deep coma after the second injury. In every case, the athlete had ongoing symptoms (e.g., headache, dizziness) prior to the second hit. Four of the cases resulted in death while six resulted in severe neurological deficits (Cantu & Gean, 2010). It is worth noting that most, if not all cases of SIS have occurred in athletes under the age of 25.

Chronic Traumatic Encephalopathy. Chronic Traumatic Encephalopathy (CTE), by contrast, was originally documented by Martland in 1928 as “punch drunk” syndrome because it was believed that only boxers suffered from the disease. However, CTE has been a major area of focus in concussion research over the past nine years because of studies in 2005 where researchers discovered evidence of CTE in football players. Omalu et al. (2005) found evidence of a reduction in overall brain weight as well as other gross and microscopic pathological findings consistent with CTE, such as cerebral tauopathy and atrophy of other brain structures (i.e., corpus callosum).

Since Omalu et al. (2005) first documented their CTE findings, research into the pathological process of CTE has intensified, revealing consistent findings associated with tau (“a protein that binds to and regulates the assembly and stability of neuronal microtubules;” Tau, 2015) deposits in human neurons. Excess tau proteins collect in neurons forming neurofibrillary tangles (NFTs). These NFTs interfere with cell communication and eventually cells die. Additionally, the clinical symptoms of CTE have been documented to include: affective disturbances, behavioral changes, psychotic symptoms, memory loss, Parkinsonism, cognitive dysfunction, and speech and gait abnormalities (Corsellis, Bruton, & Freeman-Browne, 1973). There have been three recent case studies in the medical literature documenting CTE in retired NFL football players, with the most recent study’s findings released in 2010 (Omalu, Hamilton, Kamboh, DeKosky, & Bailes, 2010). Omalu et al. (2010) followed up on previous findings that the brains of the deceased football players demonstrated CTE with evidence of cerebral tauopathy. All three players experienced neuropsychiatric impairment prior to committing suicide, in addition to impaired memory. Omalu et al. (2010) postulate that the link between CTE and chronic head trauma (even sub-concussive) is causal in nature. However, the current research is not strong enough to substantiate a causal link. As of 2009, there have been 47 cases of neuropathologically defined CTE in the literature (McKee et al., 2009).

Additional cognitive and psychological problems. Research using neurocognitive testing has demonstrated additional problems associated with multiple concussions. For example, Iverson, Gaetz, Lovell, and Collins (2004) investigated the effect of multiple concussions on amateur athletes where the authors compared a group of concussed athletes without a prior history of concussion to a group of concussed athletes with history of three or more concussions. Participants were compared on numerous variables including: subjective symptoms (Post Concussion Symptom Scale [PCSS]), reaction time, processing speed, and memory. There were large differences in subjective symptoms scores at baseline and post-injury between the groups. In addition, there were significant differences between the groups in memory performance at post-injury (Iverson et al., 2004).

Using a sample of 2905 collegiate football players, Guskiewicz et al. (2003) examined how the presence of a previous concussion influenced the likelihood of experiencing future concussions. At the end of their three-year prospective study, 184 (6.3%) players had sustained a concussion and 12 (6.5%) sustained a repeat concussion within the same season. Of the 184 players who sustained a concussion, 66 (35.8%) had a positive history of concussion (41 had 1 previous concussion, 15 had 2 previous concussions, and 10 had three or more previous concussions). Athletes who had a positive history of three or more concussions were 3 times more likely to sustain a concussion (95% CI, 1.5-5.6). Additionally, athletes with a positive history of concussion took longer to recover than athletes with no concussion history ($P = .03$, Fishers exact test). The authors concluded that multiple concussions can increase the likelihood of sustaining a future concussion as well as a longer recovery time (Guskiewicz et al., 2003).

Another study conducted by Guskiewicz et al. (2005) looked at prevalence of concussion in a sample of 2,552 retired National Football League (NFL) players. They also analyzed the association between multiple concussions and prevalence of mild cognitive impairment (MCI) and Alzheimer's disease (AD) in a subset of 758 retired NFL players. All players had played for at least two years, were aged 50 years or older, and at the time of the study they were administered two self-report questionnaires four months apart: a general health survey and subsequently an instrument focusing on cognitive decline. Of the 2,552 subjects who filled out the general health survey, 758 completed the instrument focusing on cognitive decline. An informant (spouse or relative) also filled out the instrument on cognitive functioning (note: 641 of the 758 players had an informant fill out the instrument on cogntive functioning). MCI was defined according to American Academy of Neurology Practice Parameter (30): "memory complaint corroborated by a family member; objective memory impairment as determined by neurocognitive testing; intact activities of daily living; and does not meet accepted diagnostic criteria for probable AD or other forms of dementia" (Guskiewicz et al., p. 721, 2005). Their results demonstrated that out of the sample of 2,552 retired athletes, 61% of the former NFL players had sustained at least one concussion and approxiamtely 24% sustained three or more concussions. When examining the subset of players who filled out instruments on cognitive impairment (n = 758) the authors found a significant association between recurrent concussion and clinically diagnosed MCI (chi squared = 7.82, df = 2, $p = 0.02$) and self-reported significant memory impairments (chi squared = 19.75, df = 2, $p = 0.001$). However, there was not a significant association between Alzheimer's disease and recurrent concussion (Guskiewicz et al., 2005).

A subsequent study by Guskiewicz et al. (2007) utilized the sample from Guskiewicz et al. (2005) and was designed to explore the association of depression and concussion. Two hundred and sixty-nine (11.1%) out of 2,552 retired NFL athletes reported a current or prior diagnosis of clinical depression. Considering a portion of the sample had experienced, or was currently experiencing, depression, the association with concussion was explored. The authors determined there was a significant association between multiple concussions and diagnosis of lifetime depression (chi squared = 71.21, df = 2, $p < 0.005$), suggesting a link between multiple concussions and depression.

Combined, the results from the aforementioned studies support the notion that concussions have deleterious, acute effects, but also lend support to the idea that concussive injuries may result in long-term negative consequences. Specifically, it appears that multiple concussions across an athlete's career may result in more significant impairments later in life.

Diagnostic Concerns

Rates of sports-related concussions in the United States have been estimated to be as high as 4 million per year (Barkhoudarian et al., 2011). As previously discussed, concussions are an idiosyncratic injury and, as such, diagnosis relies heavily on clinical judgment. One of the biggest factors that a clinician has to take into account when diagnosing and treating an athlete is the athlete's desire to return to competition. It is this desire, combined with the subtle neurological damage caused by a concussion that creates a difficult management process and may subsequently leave athletes susceptible to the dangers associated with repeated concussive injuries that were described in the preceding section. Previous RTP protocols relied almost exclusively on self-reported symptoms (e.g., headache, dizziness, etc.) and the primary treatment for symptomatic athletes was rest. After a clinician judged that the injured athlete was asymptomatic (based on the athlete's self-report), the athlete was allowed to return to play, sometimes as soon as 15 minutes post-injury (Lovell et al., 2004a). However, as Lovell et al. (2004a) have noted, solely relying on an athlete's self-report of their current symptoms can result in them returning to play too quickly and risking possible long-term neurological damage as well as some of the complications associated with concussion that are described above. Conversely, the total elimination of self-report from the diagnostic process is also unwise, as input from the athlete is regularly needed during the standard return to play process.

Further contributing to the problems surrounding the diagnosis of concussions was the historical practice of using concussion grading scales. Grading scales were, in fact, one of the most widely used tools for qualifying the severity of a concussion and most scales were set up with three sequential "grades" that represented concussion severity along a continuum. Unfortunately, a multitude of grading scales were developed, resulting in scales that often overlapped and conflicted (Cantu, 2001). In terms of treating a diagnosed concussion, confusion on which grading scale to use negatively impacted treatment. Moreover, recent research has shown that even a mild concussion (i.e., grade one) may have neurological symptoms that last much longer than any grading scale would have predicted. For example, Lovell, Collins, Iverson, Johnston, and Bradley (2004b) determined that athletes diagnosed with a grade one, or "ding" concussion, had symptoms that persisted throughout the first week post-injury. Their memory scores from the ImPACT test were significantly reduced ($F (2, 41) = 5.9$, $P < .007$, epsilon $> .93$, eta squared $= .22$) and did not return to baseline until an average of six days later (Lovell et al., 2004b). This is a key finding as many athletes who suffered grade one or "ding" concussions were mistakenly allowed to RTP shortly after the injury if their sideline evaluation revealed that they were symptom free after 15 minutes. More specifically, while their self-report symptoms may have disappeared, we now know that there were still unresolved neurological issues that needed to be correctly managed.

Diagnostic guidelines and severity assessment. It is important to examine the process by which the current guidelines were developed and to highlight the importance of athlete self-report. Recognizing the difficulty in diagnosing, managing, and treating concussions, a world-wide conference was convened in 2001 in Vienna, Austria with the intention of developing universal recommendations and guidelines surrounding athletes who sustain a concussion. The First International Conference on Concussion in Sport (ICCS) was organized by the International Ice Hockey Federation (IIHF), the Federation Internationale de Football Association Medical Assessment and Research Centre (FIFA, F-MARC), and the International Olympic Committee (IOC) Medical Commission. The main goals of the conference were to ensure the safety of concussed athletes and to create better standards of diagnosing and treating injured athletes. They established ten protocols (clinical history, evaluation, neuropsychological testing, imaging procedures, research methods, management and rehabilitation, prevention, education, future directions, and medico-legal considerations) to emphasize an all-inclusive diagnostic effort (Aubry et al., 2002). It is important to note that part of the recommended evaluation protocols included assessing for self-reported symptoms as well as the abandonment of the current grading systems to classify concussion severity.

The second ICCS conference was held three years later (2004) in Prague, Czech Republic. The conference re-visited many of the components of the first symposium, however, one of the new initiatives presented in Prague was the need for further research into the effects of concussions on younger children (McCrory et al., 2005). This was based on practitioners' experience with younger athletes and their symptom duration following a concussion as well as the notion that youth sport and high school athletes are more susceptible to the negative consequences associated with brain injury (especially mild) given that their brains have not completely matured (Giza & Hovda, 2001).

The third ICCS conference took place in Zurich, Switzerland in 2008. The focus of this conference was to examine the need for sideline testing (in order to examine symptom presentation immediately after a suspected concussion) and to evaluate whether cognitive assessment was needed for both elite and non-elite athletes as well as who should interpret the cognitive assessments. Regarding sideline testing, they recommended that a trained healthcare professional assess the injured player and that if no such person was available, the player should be removed from the field and taken to the closest healthcare facility for evaluation. Further, they recommended a cognitive evaluation, such as a neuropsychological test, be used for any athlete that was suspected to have sustained a concussion. They also suggested that a player should not be allowed to return to play on the same day of the injury, especially for athletes under the age of 18. All of their recommendations applied to every level of athletics, regardless of whether participants were elite or non-elite athletes (McCrory et al., 2009). Also, due to the psychological factors like depression and anxiety that have been found to be associated with Post-Concussion Syndrome (Lima, Simao Filho, Abib Sde, & de Figueiredo, 2008), recommendations to include psychologists in the treatment of concussions were made. Additionally, the National Academy of Neuropsychology (NAN) issued a position statement in 2007 regarding neuropsychological evaluation of sport-related concussion. In the position paper, the authors discussed the importance of baseline and post-injury testing. Specifically, they highlighted that "baseline evaluation is not meant to represent a comprehensive assessment but is targeted to assess cognitive domains that are most often affected by concussion, such as memory, attention, speed of mental processing, and reaction time" (Moser et al., 2007, p. 910). NAN also recommended serial post-injury evaluations to determine when neurocognitive symptoms are no longer present (Moser et al., 2007).

The most recent international conference on concussion returned to Zurich in 2012. One of the aims of the conference was to revisit past hypotheses in regards to concussion severity. The findings of the most recent ICCS supplemented those of previous conferences. For example, whereas time of LOC in moderate to severe brain injury has significant prognostic value (Jennett & Bond, 1975), in concussion, LOC has not been a good predictor of severity. A consensus was reached determining that any LOC of less than one minute would result in similar management as athletes who did not sustain LOC (McCrory et al., 2013). Additionally, it was previously believed that post-traumatic amnesia (retrograde or anterograde) was an acceptable measure of concussion severity. However, some research has suggested that the severity and duration of post-concussive symptoms are much more predictive of outcomes than solely relying on amnesia duration during the acute phase of the injury (Lovell et al., 2003; Leininger, Gramling, Farrell, Kreutzer, & Peck, 1990). The conference also reported on equipment and the role it plays in prevention. The ICCS also took a position on athletic equipment (i.e., helmets), stating that, to date, there is no strong evidence that current equipment can prevent a concussion (McCory et al., 2013). Additionally, many previous suggestions (such as the use of neuropsychological testing and return to play protocol) were unanimously supported as the evidence in favor of such suggestions grew substantially in the years since the previous conference. Baseline testing, while not recommended as a mandatory aspect of concussion management, was determined to be helpful in the interpretation of post-injury test results (McCrory et al., 2013). According to the most recent ICCS, a diagnosis of concussion will include one or more of the following: somatic, cognitive, and/or emotional self-reported symptoms, physical signs (e.g., LOC), behavioral changes (e.g., irritability), cognitive impairments, and sleep disturbance (McCrory et al., 2013). One key aspect of these recommendations that cannot be overlooked is the continued need for accurate predictors of concussion effects as well as complexities associated with prognosis and RTP times. According to the ICCS, “a range of modifying factors may influence investigation and management of concussion, and in some cases, may predict the potential for prolonged or persistent symptoms. However, the evidence for their efficacy is limited” (McCrory et al., p. 93, 2013). Accordingly, evidence for factors that influence prognosis is critical.

Return to play guidelines. The most current RTP guidelines for concussion were outlined in the fourth ICCS in 2012. The guidelines outline a six-step process that an athlete is expected to endure before being allowed to return to the playing field. The first step is rest, where the objective is to alleviate all cognitive, emotional, and physical symptoms. The athlete is generally instructed not to engage in any physical or cognitive exertion at this time and their cognitive, emotional, and physical symptoms are usually assessed using a self-report measure. The second step is gradual return to light aerobic exercise (e.g., walking or cycling), with the goal being to see if the athlete experiences a return of symptoms as his or her heart rate increases. Step three allows the athlete to engage in sport-specific exercise (e.g., running or skating) to determine if increased movement results in the provocation of concussion symptoms. During step four, the athlete engages in non-contact training/complex drills (e.g., pass routes or heavy lifting) as a means of determining how the athlete responds to strenuous exercise and cognitive load. After a medical clearance, step five includes full-contact return to practice, which allows the athlete to experience game-like conditions under supervision. Most importantly, the athlete must be able to perform each step while remaining symptom-free for 24 hours before progressing from one step to the next. Steps can be completed in a day, but if symptoms return at any point during the RTP process, the athlete is instructed to stop exertion and wait until they achieve an asymptomatic status for 24 hours before beginning the entire process again. Once an athlete has completed all five steps without a return of symptoms, the athlete is then cleared to RTP in game conditions (McCrory et al., 2013). While the ICCS outlined the recommended six step RTP process and addressed individual factors predictive of concussion severity, further empirical exploration of individual factors is needed to more reliably predict RTP times.

Factors associated with severity of concussion. While the fourth ICCS summarized the current research and protocols related to concussion in sport, it is important to further analyze the literature as it relates to severity and prognosis of concussion. The importance of an accurate prognosis after being diagnosed with a concussion cannot be underestimated, as small differences in recovery times (e.g., one day) may mean unnecessarily missing an important sporting competition or potentially exposing individuals to a risk for additional injury prior to the complete resolution of their brain injury. As such, much of the early research into prognosis and recovery time was formulated to investigate and classify concussion severity.

The original attempt to predict prognostic outcomes in concussion involved the use of grading systems. More specifically, grading systems were created and adopted in order to assist clinicians in managing the injury. While many grading systems were created, the American Academy of Neuroscience (AAN; Report of the Quality Standards Subcommittee, 1997) conducted one of the first comprehensive reviews on concussion in sport. Based on an extensive literature review combined with expertise from those familiar with the injury (e.g., neurologists, neurosurgeons, sports medicine physicians, psychiatrists, neuropsychologists, athletic trainers, and players) the AAN grading system was developed (Report of the Quality Standards Subcommittee, 1997) and is presented in Table 1.

Table 1

AAN Grading System for Concussion

Grade 1	Transient confusion; no loss of consciousness; concussion symptoms or mental status abnormalities on examination resolve in less than 15 minutes
Grade 2	Transient confusion; no loss of consciousness; concussion symptoms or mental status abnormalities on examination resolve in more than 15 minutes
Grade 3	Any loss of consciousness, either brief (seconds) or prolonged (minutes)

Retrieved from: Report of the Quality Standards Subcommittee, p. 582, 1997

Along with the grading system, AAN also provided recommendations for how a player should be returned to competition after sustaining a concussion. If a player sustained a Grade 1 concussion, he or she could be returned to play in the same contest as long as his or her symptoms remitted within fifteen minutes. For a Grade 2 concussion, it was recommended that the athlete be removed from the competition and not allowed to return to play until he or she was asymptomatic for at least one week at rest and with exertion. Finally, for a Grade 3 concussion, the athlete should be removed from the competition and evaluated at an emergency department. If the athlete’s LOC was brief (seconds) he or she could be allowed to return to play after remaining asymptomatic for at least one week at rest and with exertion. If the athlete’s LOC was prolonged (minutes), it was recommended that the athlete be withheld from competition until he or she has been asymptomatic for at least two weeks at rest and with exertion (Report of the Quality Standards Subcommittee, 1997). The inclusion of LOC as a predictor of severity was based on past studies that investigated biomechanical forces in head injury in animals as well as current expert opinion at the time (Lovell, Iverson, Collins, McKeag, & Maroon, 1999).

Given the role that LOC had in the AAN grading system (as well as many other grading systems), several studies evaluated LOC as a predictior of severity. Lovell et al., (1999) evaluated the effect that LOC had on neuropsychological performance. The authors evaluated three groups of individuals (LOC, no LOC, and LOC unknown) who had sustained a non-sports related mTBI in multiple areas of neuropsychological performance including: attentional processes, visual scanning, information processing, verbal and visual memory, motor coordination, and speech fluency. Patients were selected from trauma service at a Pennsylvania hospital and were included in the study if they had a Glasgow Coma Scale (a scale used to assess severity of brain injury; Glasgow Coma Scale, 2015) score of 14 or 15 (13-15 is the range for mTBI). Exclusion criteria included: presence of skull fracture, intracranial abnormality demonstrated by CT scan, post-traumatic amnesia, age older than 45, missing LOC data, and neuropsychological testing completed more than 7 days after the injury. Three hundred and eighty three individuals were included in the study (LOC = 229, no LOC = 78, LOC unknown = 76). The authors performed multiple univariate analysis of variances (ANOVAs) to test for between group differences on all areas of neuropsychological performance studied. No between-group statistical differences for any of the areas tested were found, leading Lovell et al. (1999), to conclude that LOC should not be weighed any heavier in determining severity than other markers of concussion.

In Kelly’s (2003) review of the LOC literature, he maintained that the literature supported the use of LOC as an important factor in deciding if the athlete should return to play the day of the competition. That is, within minutes after the injury, assessing for LOC plays a role in immediate decision making. However, in terms of long term prognosis, “rates of recovery vary from individual to individual” (Kelly, 2003, p. 252). Collins et al. (2003) determined that on-field presence of LOC did not result in differences in neuropsycholgical functioning or symptoms presentation when assessing the athlete at 2 days post injury. However, on-field symptoms of amnesia was predictive of both neuropsycholgical performance and symptom presentation. At two days post- injury, athletes who reported on-field retrograde amnesia were 10 times more likely to have pronounced post-concussion symptoms and memory deficits (Collins et al., 2003).

Many problems relating to assessing concussion severity stem from the retrospective nature of assessment. Traditionally, it has been difficult to predict how long an athlete will be out of play. While grading scales were an initial attempt to simplify the process, such scales did not fare as well in practice due to the idiosyncratic nature of recovery time. As such, in 2001 the ICCS abandoned the use of grading scales and called for a better categorization of concussion (Aubry et al., 2002). Ironically, the ICCS adopted the use of a different concussion classification system in 2004: simple and complex concussion, whereby an athlete who recovered within 7-10 days of their injury without complication was deemed to have sustained a “simple” concussion. Those who suffered persistent symptoms and cognitive impairment as well as prolonged LOC (i.e., greater than one minute) or multiple previous concussions were said to have suffered a “complex” concussion (McCrory et al., 2005).

Lau, Lovell, Collins, and Pardini (2009) examined recovery time using the simple and complex classification system by evaluating data from 108 recently concussed male high school football players (ages 13-19, mean = 16.1) gathered over a 5-year span. Forty-seven (43.5%) were classified as simple concussions and 61 (56.5%) were classified as complex concussions. The average time between injury and test for the sample was 2.2 days, with the medium time for both groups equal to 2 days and signifying no difference between groups. Outcome measures were taken from the ImPACT test and a multivariate analysis of variance (MANOVA) was run to evaluate for differences in neuropsychological functioning (verbal memory, visual memory, reaction time, visual motor speed) between simple and complex concussion groups. The overall MANOVA was significant ($F = 2.69$, $p = .04$) and follow-up ANOVAs determined that visual memory ($F = 6.68$, $p = .016$) and processing speed ($F = 7.92$, $p = .007$) were significantly worse in complex than in simple concussions. However, the simple/complex concussion classification was still done retrospectively. So while the authors were able to retrospectively understand the differences between simple and complex concussions based on neurocognitive performance, there remains a void in reliable predictive information for the severity of the concussion in terms of actual number of RTP days.

Predicting Return to Play

While many studies have examined the effects of different concussion markers (e.g., amnesia, LOC) on neuropsychological performance or symptom presentation, few have evaluated their effect on RTP. Asplund, McKead, and Olsen (2004) evaluated the predictive value of concussion signs and symptoms, specifically LOC, retrograde amnesia, anterograde amnesia, headache, difficulty remembering, and difficulty concentrating for two groups: RTP time less than or equal to 7 days and greater than 7 days. The authors mailed a survey instrument to 43 primary care sports providers managing sports-related concussion. The survey assessed demographics, mechanism of injury, portion of the contest, site evaluation, occurrence and duration of concussion symptoms, final disposition of the patient, and time for RTP. After excluding 13 surveys due to missing data, 101 surveys of athletes from multiple sports and levels of participation were included in the analysis. A Pearson chi-squared analysis was employed using concussion signs and symptoms and demographics as independent variables and RTP as the dependent variable. Asplund et al. (2004) determined that the presence of headaches and concentration and memory problems that lasted more than 3 hours post- injury correctly predicted longer RTP (>7 days). Additionally, the authors determined that the presence of retrograde amnesia and LOC resulted in longer RTP (>7 days). Again, this study differed from previous studies in that it did not use neuropsychological impairment or concussion symptoms as outcomes, rather it assessed RTP time. Asplund et al. (2004) also used a population of high school athletes, which differed from the collegiate or professional athlete populations that had mostly been studied up to that point.

While Asplund et al. (2004) demonstrated differences in groups based on a cutoff of a RTP of 7 days, other studies have suggested that deficits due to concussion, such as neurocognitive deficits (e.g., verbal memory), may persist longer. For example, McClincy, Lovell, Pardini, Collins, and Stroke (2006) examined ImPACT scores for 104 high school and college athletes who had completed a baseline screening, been diagnosed with a concussion, and had three follow-up testing sessions post-injury. The three testing points were, on average, day 2, day 7, and day 14 post-injury. The authors evaluated testing performance using the four neurocognitive composite scores (verbal memory, visual memory, reaction time, and processing speed) as well as post-concussion symptoms. A MANOVA model was employed to evaluate how the neurocognitive data was related to RTP time. Main effect differences were found across the evaluation period for verbal memory ($F[3,309] = 37.74$, $p < .01$), visual memory ($F[3,225] = 19.05$, $p < .01$), processing speed ($F[3,309] = 26.74$, $p < .01$), and reaction time ($F[3,309] = 28.07$, $p < .01$). Pairwise comparisons were analyzed to evaluate differences between baseline and post-test scores at each time point. For verbal memory, significant differences were found at day 2 ($p < .01$), day 7 ($p < .01$) and day 14 ($p < .01$). For visual memory, differences were found at day 2 ($p < .01$) and day 7 ($p < .01$), but not at day 14. For processing speed, differences were found at day 2 ($p < .01$), and for reaction time, differences were found at day 2 ($p < .01$) and day 7 ($p < .01$), but not at day 14 (McClincy et al., 2006). The results from the study demonstrated that neurocognitive symptoms of concussion can last up to 14 days, potentially signifying that Asplund et al.'s (2004) cutoff of seven days is not sufficient.

In Lau, Kontos, Collins, Mucha, and Lovell (2011), the authors investigated how on-field signs and symptoms (i.e., signs and symptoms immediately after injury) related to RTP by investigating 104 male high school football players who sustained concussions during the pre-season or regular season. Other inclusion criteria included documented and observed on-field signs and symptoms of concussion by trained medical staff and evaluation and follow-up by clinical members of the research team. Exclusion criteria included current or history of brain surgery, substance abuse, or other neurological disorders (e.g., seizure, psychiatric diagnoses, etc.). In order to highlight stark differences in RTP times, Lau et al. (2011) split the sample into two groups: quick recovery (RTP less than or equal to 7 days) and protracted recovery (RTP greater than or equal to 21 days). A series of odds ratios with chi-squared analyses were used to identify which on- field signs/symptoms of concussion were associated with protracted recovery. The authors found that on-field dizziness was the only sign or symptom associated with protracted recovery (OR = 6.4, 95% confidence interval = 1.39-29.70, chi squared = 6.97, $p = .01$; Lau et al., 2011). However, as important as this finding is, the authors excluded cases with recovery times between eight and twenty days. When it comes to the clinical significance of RTP, it is essential that research is aligned with clinical care. As such, there is room for improvement when it comes to examining the association of signs and symptoms with RTP.

Within the past ten years, researchers have begun to explore the potential impact of clusters of symptoms on RTP. Most notably, Mihalik et al. (2005) examined the effect of post-traumatic migraine symptoms (PTM; headache plus nausea, photophobia or phonophobia) on RTP and cognitive functioning. The authors evaluated data from 261 concussed athletes, which they divided into three groups: (1) PTM, (2) headache, and (3) no headache (where the headache group consisted of those who reported headaches without other migraine-like symptoms). One-way ANOVA followed by post-hoc analyses were performed to evaluate differences between groups on RTP. The authors determined that PTM is associated with longer RTP times and reduced neurocognitive performance (verbal and visual memory, reaction time, and processing speed) when compared to athletes who had headaches without migraine symptoms or athletes without headaches (but who reported other symptoms) and when compared to baseline scores.

Most recently, Kontos et al. (2013) replicated this finding in a sample of 138 male high school football players. The authors used a series of 3 (PTM, headache, no headache) X 3 (pre-injury, post-injury 1-7 days, post-injury 8-14 days) ANOVAs with post-hoc Scheffé tests to evaluate differences between cognitive performance on the ImPACT composite scores and post-concussion symptoms. It was determined that the PTM group performed worse on verbal memory than the no headache group at 8-14 days post-injury. Whereas the PTM group performed worse than both other groups at 1-7 days and 8-14 days post-injury on visual memory, reaction time, and total concussion symptoms. They also determined that athletes who reported PTM symptoms were 7.3 (95% confidence interval = 1.8-29.91) times more likely to require more than 20 days to RTP when compared to athletes who did not report headaches. Also, when compared to athletes who reported headache without migraine symptoms, athletes who reported

PTM symptoms were 2.6 (95% confidence interval = 1.10-6.54) times as likely to have RTP times more than 20 days (Kontos et al., 2013).

Given the evidence supporting the temporal relationship between concussion symptoms and neurocognitive deficits in athletes who have sustained a concussion, it is clear that factors predicting RTP time could be further investigated. While much of the research up to this point has evaluated individual predictors of concussion severity, few studies have thought to examine multiple predictors simultaneously or to combine groups of symptom presentations in an effort to predict RTP. Given the paucity of research in this area, the goals of the current study are to evaluate the predictability of RTP times based on self-reported concussion symptoms, as well evaluate the ability to predict RTP time based on both combinations of concussion symptoms and neurocognitive performance. It is expected that the results of this study will supplement current research on the clinical management of sports-related concussion by providing clinicians with more accurate prognostic information and potentially provide clinicians with a method to more accurately predict RTP times.

Hypotheses

Purpose. This study will explore how a combined set of substantively and empirically derived variables are related to severity of concussion. More specifically, variables including raw score (e.g., 0-6) of 8 self-reported post-injury symptoms from the PCSS (headache [HA], nausea [NAU], difficulty remembering [DR], feeling mentally foggy [FOG], difficulty concentrating [DC], dizziness [DZ], sensitivity to light [STL], and sensitivity to noise [STN]), four neurocognitive post-injury composite scores (verbal memory [VERM], visual memory [VISM], visual motor speed [VMS], and reaction time [RT]), as well as demographic variables (age [AGE], days between injury and test [DBIT], and number of previous concussions [#CON]) will be included in a XXXXX XXXX to create a model designed to predict RTP time. Accordingly, the purpose of this study is to predict expected RTP time based on the previously defined set of variables associated with severity of concussion.

To achieve the purpose, this study will evaluate four research questions: (1) Can the number of days out due to injury be predicted by the combination of demographic variables, post-concussion symptoms, and post-concussion neurocognitive performance? (2) Which variables significantly predict RTP time after accounting for other variables included in the model? (3) What is the correlation between RTP time predicted by the model and observed days out? (4) Is the original model stable across samples? The specific hypotheses as they relate to the research questions are as follows:

H_1: Number of days out of play can be predicted by a set of demographic characteristics, self-reported post-injury concussion symptoms, and post-injury neurocognitive functioning.

H_2: Variables empirically derived will provide a unique and significant contribution to predicting return to play time.

H_3: There will be a correlation between predicted RTP time and observed RTP time.

H_4: The regression equation derived from the validation sample will be stable across samples.

CHAPTER III

Methodology

Participants

Participants were drawn from 382 athletes that sought diagnosis and management of a sports-related concussion at the Nova Southeastern University Sports Medicine Clinic (NSU-SMC). As part of their evaluation, participants completed a comprehensive medical evaluation, a neurocognitive screening (ImPACT), and a psychological clinical interview. Participants were included in the study if the team of treating professionals (medical doctor and psychologist) diagnosed them with a concussion based on current diagnostic guidelines. Additional inclusion criteria included: participant was evaluated within 60 days of sustaining the injury, participant returned to play within 60 days of the injury, and participant completed the ImPACT (Immediate Post-Assessment and Cognitive Testing) test in English. The study was approved by the Institutional Review Board (IRB) at Nova Southeastern University (NSU) on 07/25/2014.

Two hundred and seventy three athletes (207 males; 66 females) ranging in age from 13 to 22, with a mean age of 16.36 ($\sigma = 1.69$) met inclusion criteria for the study. Of these individuals, 226 participants were in high school at the time of the injury, 31 were in college, 14 were in junior high school, and 1 was participating in professional sports (1 participant had missing data). Mean days out of play (i.e., days between date of concussion and RTP) was 20.86 ($\sigma = 9.88$) and mean days between date of concussion and initial test date was 8.22 ($\sigma = 6.96$). See Table 2 for demographic characteristics.

Table 2

Demographics and Other Characteristics of Concussed Athletes

Characteristic	*n*	%
Gender		
Male	207	75.8
Female	66	24.2
Sport		
Football	155	56.8
Soccer	27	9.8
Lacrosse	24	8.7
Basketball	18	6.6
Softball	10	3.7
Wrestling	7	2.6
Cheerleading	6	2.2
Volleyball	5	1.8
Swimming	5	1.8
Baseball	4	1.5
Tennis	2	0.7
Rowing	2	0.7
Ice Hockey	2	0.7
Track & Field	1	0.4
Gymnastics	1	0.4
Diving	1	0.4
Water Polo	1	0.4
Sailing	1	0.4
Band	1	0.4
Education Level		
Junior High School	14	5.1
High School	226	82.8
College	31	11.3
Professional	1	0.4
Missing	1	0.4

Measures

The ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing) test was utilized to assess cognitive functioning for participants primarily because the ImPACT test was developed to assist practitioners in making informed decisions regarding RTP after an athlete was suspected of sustaining a concussion. The test itself is comprised of the three sections (Demographics Profile and Health History Questionnaire; Current Concussion Symptoms and Conditions; Neurocognitive Tests) that are described below.

ImPACT sections.

Demographics profile and health history questionnaire. The first section of ImPACT requires the athlete to input basic demographic and descriptive information using a computer keyboard and mouse to navigate/select responses on the screen. For example, this section asks athletes to answer questions regarding height, weight, sport played, and position as well as concussion and health history (e.g., history of neurological disorders, brain surgery, psychiatric disorders, etc.). It then asks questions about the most recent date of concussion, hours slept the previous night, and current medications (ImPACT®, 2012).

Current concussion symptoms and conditions. In section two of the ImPACT test, the athlete self-rates the severity of 22 concussion symptoms they have experienced in the previous 24 hours (see PCSS in Appendix). The PCSS uses a 7-point rating scale (0 = absence of symptom, 1-2 = mild, 3-4 = moderate, 5-6 = severe) which are summed into a total symptom score. The symptoms are presented on the computer screen and the athlete uses the mouse to click a circle that corresponds to the appropriate number (e.g., 3 for moderate symptom severity; ImPACT®, 2012).

Neurocognitive tests. In section three of ImPACT, athletes complete six modules that test neurocognitive functioning: Word Memory, Design Memory, X's and O's, Symbol Match, Color Match, and Three Letters. See Table 3 for ImPACT module descriptions.

Each ImPACT module serves as a subscale in the development of four composite scores (Verbal Memory [VERM], Visual Memory [VISM], Visual Motor Speed [VMS], and Reaction Time [RT]) that estimate neurocognitive functioning (ImPACT®, 2012). Subscales yield numerous subscores representing accuracy and speed of response. Each raw composite score is calculated based on an equation combining subscores of the different ImPACT subscales. The score is then calculated into a percentile rank based on the ImPACT age-appropriate normative data. See Table 4 for neurocognitive composite score equations.

In terms of concussion management, either the raw composite score or its associated percentile rank is compared to the athlete's baseline score or to age-appropriate norms if no baseline score is available. Significant differences between baseline composite scores (or normative composite scores) and post-injury scores are derived using reliable change indexes (RCI) provided by the ImPACT test developers. Each composite score has a different RCI (VERM ≥ 9 points, VISM ≥ 14 points, VMS ≥ 5 points, RT ≥ .06 seconds, and PCSS ≥ 10 points; Iverson, Lovell, & Collins, 2003). See Reliability and Validity of ImPACT for information on calculating RCIs. In order for an athlete to be cleared to begin the RTP protocol, it is expected that baseline or normative scores must be met and that the athlete has been symptom free at rest (McCrory et al., 2013).

Table 3

ImPACT Module Descriptions

Module	Description
Word Memory	Evaluates attentional processes and verbal recognition memory using a word discrimination paradigm
Design Memory	Evaluates attentional processes and visual recognition memory using a design discrimination paradigm
X’s and O’s	Measures visual and working memory as well as visual processing speed and consists of a visual memory paradigm with a distractor task that measures response speed
Symbol Match	Evaluates visual processing speed, learning, and memory
Color Match	Represents a choice reaction time task and also measures impulse control and response inhibition
Three Letters	Measures working memory and visual response speed

Retrieved from: The ImPACT Test, 2014

Table 4

Neurocognitive Composite Score Calculations

Composite Score	Calculation
VERM	[Total Word Memory % Correct + Symbol Match (Total correct hidden/9)*100 + Three Letters % Total Letter Correct] / 3
VISM	[Design Memory Total % Correct + (X’s and O’s Total Correct Memory/12)*100] / 2
VMS	[(X’s and O’s Total Correct Interference/4) + (Three Letters Average Counted Correctly*3)] / 2
RT	[X’s and O’s Average Correct RT Interference + (Symbol Match Average Correct RT Visible/3) + Color Match Average Correct RT] / 3

Retrieved from: The ImPACT Test, 2014

Reliability and Validity of ImPACT. Moser et al. (2007) highlighted that the model of neuropsychological assessment in sports-related concussion is different from traditional, extensive, time-consuming neuropsychological batteries. Therefore, the use of a neurocognitive screening instrument, such as ImPACT, meets the needs of a standard sports-related concussion evaluation in that it evaluates memory, visual motor speed, and reaction time. It is not designed as a full neuropsychological battery, rather a screener used to aid diagnosis and management.

One of the original studies examining the psychometric properties of the ImPACT was conducted by Iverson et al. in 2003. They examined test-retest reliability as well as reliable change confidence intervals using two samples. The first sample comprised of 56 non-concussed athletes (mean age = 17.6; mean test-retest interval = 5.8 days). The second sample comprised of 41 concussed athletes (mean age = 16.8) who had taken a baseline ImPACT preseason as well as a post-injury ImPACT within 72 hours of their concussion. Test-retest Pearson Correlation coefficients for the non-injured sample were calculated as follows: Verbal Memory = .70, Visual Memory = .67, Reaction Time = .79, Processing Speed = .86. Reliable change estimates, calculated according to the method proposed by Jacobson and Truax (1991), were computed for the first group to examine for test-retest differences while taking into account measurement error (see Table 5 for descriptives, SEMs, S_{diffs}, and reliable change confidence intervals). There were no differences found between time one and time two test points on composite scores except for Processing Speed. The authors found a 1.7 point practice effect with 68% of the sample recording faster times at retest on the Processing Speed Index.

Table 5

Descriptive Statistics, SEMs, S_{diffs}, and Reliable Change Intervals for Healthy Control Subjects (N=56)

Composite	M (SD)		*p*	SEM_1	SEM_2	S_{diff}	CI	
	Time 1	Time 2					0.80	0.90
Verbal Memory	88.68 (9.50)	88.84 (8.09)	0.86	5.2	4.43	6.83	8.75	11.21
Visual Memory	78.70 (13.39)	77.48 (12.67)	0.4	7.69	7.28	10.59	13.55	17.37
Reaction Time	.543 (.087)	.536 (.063)	0.34	0.04	0.03	0.05	0.06	0.08
Processing Speed	40.54 (7.64)	42.24 (7.06)	0.002	2.86	2.64	3.89	4.98	6.38
PCSS	5.223 (6.75)	5.79 (10.07)	0.59	3.99	5.96	7.17	9.18	11.76

Note: SEM: standard error of measurement; S_{diff}: standard error of difference; PCSS: Post-Concussion Scale; CI: Confidence Intervals

Retrieved from: Iverson et al., p. 462, 2003

The authors used the standard error difference (S_{diff}) to determine a confidence interval for baseline-retest difference scores. The confidence interval determined the amount of change necessary to consider a person "injured" at post-injury evaluation (e.g., a significant change from their baseline score). In calculating S_{diff}, SEM for both baseline and rest was used to avoid estimating S_{diff} by multiplying the squared baseline SEM. See Table 6 for S_{diff} calculations using SEM_1 and SEM_2.

Table 6

Calculation of S_{diff} Using SEM_1 and SEM_2

Calculation	Description
$SEM_1 = SD_1 \sqrt{}1\text{-}r_{12}$	Standard deviation from time 1 multiplied by the square root of 1 minus the test-retest coefficient
$SEM_2 = SD_2 \sqrt{}1\text{-}r_{12}$	Standard deviation from time 2 multiplied by the square root of 1 minus the test-retest coefficient
$S_{diff} = SD_2 \sqrt{}SEM_1 + SEM_2$	Square root of the sum of the squared SEMs for each testing occasion

Retrieved from: Iverson, et al., p. 462, 2003

Numerous other studies have evaluated various psychometric properties of the ImPACT test. For example, Iverson, Lovell, and Collins (2005) evaluated the validity of processing speed as measured by the ImPACT visual motor speed composite score. A sample of 72 amateur athletes who sustained a concussion within 21 days of test administration were used for the study. Athletes completed the ImPACT as well as traditional paper pencil processing speed test, the Symbol Digit Modalities Test (SDMT; Smith, 1982). The SDMT requires participants to substitute a number for a geometric figure. The substitution occurs in a random series and the total number of correct substitutions in 90 seconds are added up for a final score. The processing speed composite score on ImPACT was significantly correlated with scores on SDMT ($r = .70$, $p < .001$). Additionally, the correlation coefficient for SDMT and processing speed was significantly stronger than the correlation coefficient for SDMT and verbal memory ($t = 2.69$, *p*

< .01) as well as the correlation coefficient for SDMT and reaction time (t = 2.24, $p < .05$). However, the correlation coefficient for SDMT and processing speed was not significantly stronger than the correlation coefficient for SDMT and visual memory (t – 1.43, ns). Thus, the authors concluded that the ImPACT test is sensitive to processing speed deficits at post-concussion (Iverson al., 2005).

Additionally, Schatz (2009) evaluated the long-term test-retest reliability of baseline scores on the ImPACT (although he used a different version, ImPACT 3.0). An initial sample 117 male and female collegiate athletes were administered a baseline version of the ImPACT approximately two years apart. Of the initial 117, 95 athletes were included in the study (15 were excluded for sustaining a concussion in between administrations, and seven were excluded based on erratic performance based on impulse control scores greater than 22). All four neurocognitive composite scores as well as total symptom score were evaluated for reliability statistics.

Procedure

The present study was retrospective in nature, using archival data previously collected as part of participants' clinical management of concussion. A XXXXXXXXXXXXX was utilized to create an equation that could be utilized to predict RTP time.

Participants completed a computerized version of the ImPACT test as part of their standard clinical care, with the staff at the NSU-SMC administering the ImPACT test during post-injury evaluations. The staff consisted of a licensed clinical psychologist and advanced, doctoral psychology students trained in the administration and interpretation of ImPACT. Participants completed the first section of the ImPACT (*Demographics profile and health history questionnaire*). Next, NSU-SMC staff read the instructions for section two (*Current concussion symptoms and conditions*) to the participants and answered any procedural questions.

Participants were reminded to fill out the ImPACT's PCSS based on how they felt in the preceding 24hours. After reading section two instructions, participants clicked on the appropriate rating for each of the 22 symptoms. Lastly, NSU-SMC staff read the instructions for section three (*Neurocognitive tests*) of the ImPACT and highlighted the importance of speed and accuracy for participants. After reading the instructions for the initial module of section three, participants completed the six subtests without interruption. Once the ImPACT test was completed, participants continued on with their clinical evaluation and RTP decisions were made based on the totality of their clinical evaluation.

Statistical Analyses

Archival data of participants' first post-injury evaluation was received from the ImPACT company administrators and entered on a university computer to create a de-identified data set. This data set was analyzed using the SPSS (Statistical Packages for the Social Sciences) and SAS (Statistical Analysis System) statistical packages.

Based on the goal of the study, to examine factors that predict RTP time, a quantitative approach was taken to evaluate a set of factors (the independent variables [IV]) and their influence on RTP time (the dependent variable [DV]). These factors include: raw score (e.g., 0-6) of eight self-reported symptoms from the PCSS (headache [HA], nausea [NAU], difficulty remembering [DR], feeling mentally foggy [FOG], difficulty concentrating [DC], dizziness [DZ], sensitivity to light [STL], and sensitivity to noise [STN]), the four neurocognitive composite scores at post-injury (Verbal Memory [VERM], Visual Memory [VISM], Visual Motor Speed [VMS], and Reaction Time [RT]), as well as demographic variables (age [AGE], days between injury and test [DBIT], and number of previous concussions [#CON]). It is important to note that unlike previous studies which often rely on ambiguous definitions of RTP time and categorize subjects in groups based on vague estimates of RTP time (Kontos et al., 2013; Lau et al., 2011; McClincy et al., 2006; Mihalik et al., 2005; Asplund et al., 2004), the quantitative analysis conducted herein, and in particular the XXXXXXXXXX, was chosen in order to predict a more precise estimate of the number of days an athlete will be out of play.

More specifically, the dependent variable RTP time (measured in number of days out of play) is defined in this study as the difference between the actual RTP date and date of concussion. One of this study's most unique aspects is that it offers a precise, unambiguous definition of RTP time, which relies on an exact RTP date. It is possible to obtain such a precise RTP time in the study because the State of Florida legislation, associated with high school concussions, requires clearance by a medical professional knowledgeable in concussion prior to RTP. Therefore, in order to be cleared by a medical professional, the athlete must complete the graduated RTP protocol (discussed previously), which is dictated solely by the medical professional. Once the athlete completes the protocol, a clearance form is signed outlining a RTP progression as well as the exact date of medical clearance for contact activities and live competition. Given that the state concussion legislation excludes players, parents, or coaches from the RTP decision making process, the calculation of RTP time in the present study is a more consistent and precise measurement of actual RTP.

Approximately 50% of the data was randomly chosen to form the validation group (VGRP) using the "set seed" function in SPSS, with the remaining 50% used as the cross-validation group (CVGRP). Therefore, 139 participants (104 males, 35 females) made up VGRP, and GRP 2 was comprised of 134 participants (103 males, 31 females). A series of independent samples t-tests were conducted to determine if any differences existed between groups. Sample characteristics for VGRP and CVGRP are provided in Tables 7 and 8, respectively. Descriptive and t-test statistics by group are provided in Table 9.

Accordingly, the XXXXXXXXX procedure in SAS was chosen in order to determine the “best” subset of variables that explain the DV. Unlike traditional models which do not allow for effect selection methods, XXXXXXXXX allows for model specification, selection control, as well as display and output, making it a more all-encompassing procedure. The XXXXX was chosen as the variable selection method in order to select the most parsimonious model (SAS/STAT[R] 9.2 User's Guide, 2009).

Table 7

VGRP Sample Characteristics (n=139)

Variable	Min	Max	Mean	SD
AGE	13	22	16.3	1.658
#CON	0	4	0.47	0.783
DBIT	0	38	8.18	6.795
HA	0	5	1.86	1.6
NAU	0	5	0.45	1.044
DR	0	6	0.57	1.186
DC	0	6	1.24	1.672
FOG	0	6	0.94	1.352
DZ	0	6	0.83	1.383
STL	0	5	1.09	1.535
STN	0	5	0.67	1.236
VERM	40	100	83.96	12.479
VISM	31	100	70.48	13.961
VMS	20	51	36.29	6.766
RT	0	2	0.62	0.131

Note: Males, n = 104; Females, n = 35

Table 8

CVGRP Sample Characteristics (n=134)

Variable	Min	Max	Mean	SD
AGE	13	22	16.41	1.718
#CON	0	5	0.48	0.873
DBIT	1	51	8.26	7.159
HA	0	6	1.84	1.848
NAU	0	6	0.5	1.088
DR	0	5	0.45	1.052
DC	0	6	1.19	1.6
FOG	0	5	0.93	1.442
DZ	0	6	0.76	1.367
STL	0	6	1.23	1.677
STN	0	6	1.05	1.581
VERM	56	100	85.18	10.266
VISM	29	100	74.04	14.089
VMS	17	50	35.69	6.303
RT	0	1	0.62	0.094

Note: Males, n = 103; Females, n = 31

Table 9

Descriptive and t-test Statistics by Group

Variable	VGRP Mean (SD)	CVGRP Mean (SD)	T-statistic (p-value)
AGE	16.30 (1.67)	16.41 (1.72)	-0.530 (0.597)
#CON	0.47 (0.78)	0.48 (0.87)	-0.100 (0.921)
RTP	21.37 (10.16)	20.32 (9.59)	0.880 (0.380)
DBIT	8.18 (6.80)	8.26 (7.16)	-.0096 (0.923)
HA*	1.86 (1.60)	1.84 (1.85)	0.097 (0.923)
NAU	0.45 (1.04)	0.50 (1.09)	-0.362 (0.717)
DR	0.57 (1.19)	0.45 (1.05)	0.888 (0.376)
DC	1.24 (1.67)	1.19 (1.60)	0.293 (0.770)
FOG	0.94 (1.35)	0.93 (1.44)	0.014 (0.989)
DZ	0.83 (1.38)	0.76 (1.37)	0.397 (0.691)
STL	1.09 (1.54)	1.23 (1.68)	-0.746 (0.456)
STN*	0.67 (1.24)	1.05 (1.59)	-2.235 (0.027)**
VERM	83.96 (12.48)	85.18 (10.27)	-0.877 (0.381)
VISM	70.48 (13.96)	74.04 (14.09)	-2.098 (0.037)**
VMS	36.29 (6.77)	35.69 (6.30)	0.760 (0.448)
RT	0.62 (0.13)	0.62 (0.09)	0.243 (0.809)

*Equal variances not assumed

**Significant at the $p < .05$ level

Figure 1. Distribution of RTP time for VGRP

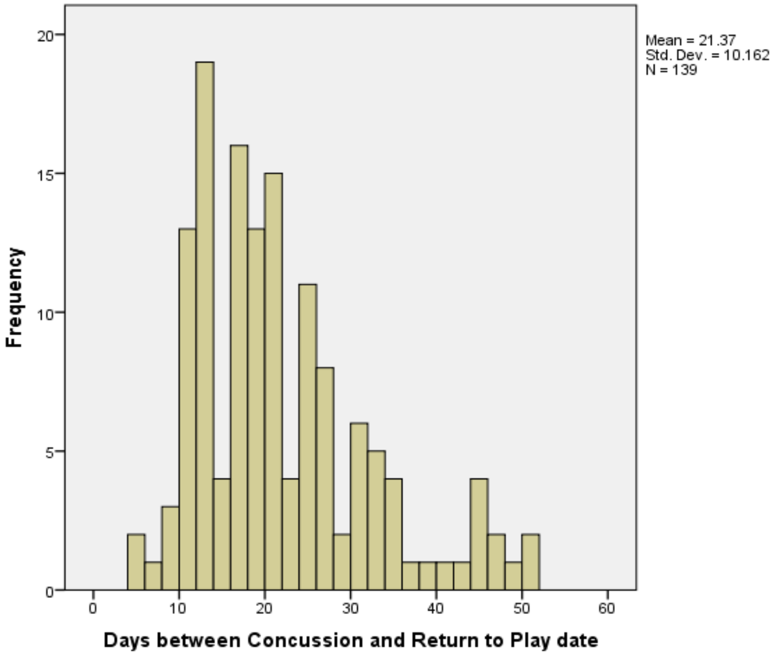
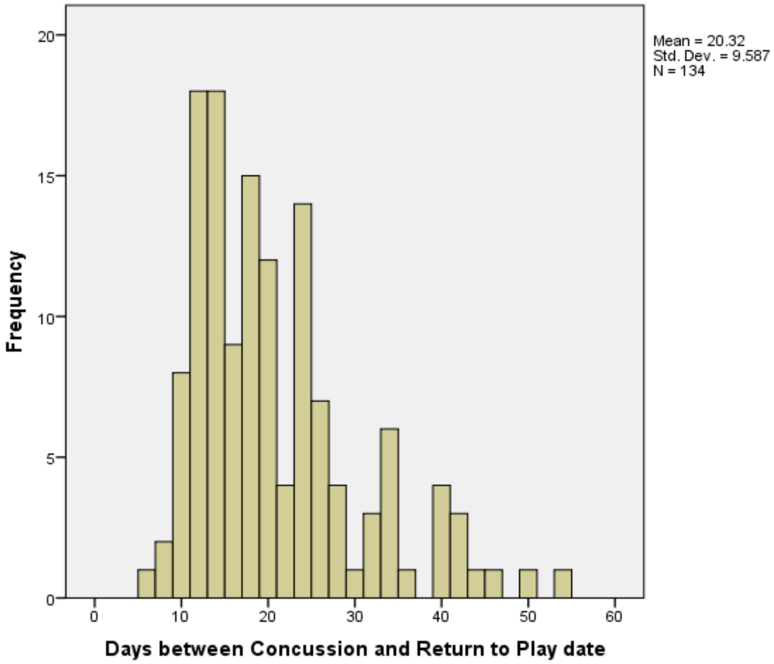


Figure 2. Distribution of RTP time for CVGRP



The (XXXX) was used in order to determine when the fit of the model is no longer improved by adding more variables. The XXXX is superior to the XXX in that the bias of the XXXX is typically smaller than that of XXX (Hurvich & Tsai, 1991). The XXXXXXXXX with XXXXX section and XXXX stop criteria resulted in the selection of the final variables to be used in evaluation of the hypotheses. For clarity, statistical analyses for hypotheses 1-3 focus on the creation of the predictive model using the VGRP while analyses for hypothesis 4 focus on validation and model stability using the CVGRP.

Hypotheses 1-3 (see page 33). Using the VGRP, XXXXXXXX was employed to determine if the overall model significantly predicted average RTP time. The results of the XXXXXXX also provided *p*-values associated with each variable which were used to assess each variable's contribution to predicting RTP time. Third, a Pearson Correlation coefficient was calculated using average predicted RTP time with observed RTP time to examine strength of the prediction equation.

Hypothesis 4 (see page 33). The predictive model was applied to the CVGRP to predict average RTP time. A Pearson Correlation coefficient was calculated using average predicted RTP time with observed RTP time to assess for model stability. Additionally, the XXXXXXXXX variable selection method was applied to the CVGRP to determine if there was consistency in variable selection across the two groups.

CHAPTER IV

Results

Hypothesis 1

Number of days out of play can be predicted by a set of demographic characteristics, self-reported post-injury concussion symptoms, and post-injury neurocognitive functioning.

A XXXXXXXX was employed using the data from VGRP to determine if the set of variables significantly predicted RTP time. A goodness of fit analysis resulted in a Pearson Chi-Squared of 9.822 (p-value = .075), indicating a good model fit. Additionally, the Omnibus test resulted in a Likelihood Ratio Chi-Squared of 166.786 (p-value <.001), indicating the model significantly predicted RTP time.

Hypothesis 2

Variables empirically derived will provide a unique and significant contribution to predicting return to play time.

The contribution of each variable in the model was evaluated by examining the *p*-values derived from the regression equation. Three of the seven variables had unique significant contribution to the DV.

Hypothesis 3

There will be a correlation between predicted RTP time and observed RTP time.

A Pearson Correlation coefficient was calculated using average RTP time as predicted by the model with observed RTP time. The resulting coefficient (r = .851, p < .001) was statistically significant at the .001 level with a large effect size (r >. 80; Cohen, 1992).

Hypothesis 4

The regression equation derived from the validation sample will be stable across samples.

Predicted RTP time was calculated for the CVGRP using the model derived by the VGRP. A Pearson Correlation coefficient was calculated by correlating average predicted RTP time with observed RTP time for the CVGRP. While the correlation coefficient dropped, the model appears to be moderately stable across samples, noting that the resulting coefficient (r = .598, $p < .001$) was also statistically significant at the .001 level with a moderate effect size ($r >$ .50; Cohen, 1992). Additionally, the same variable selection method previously utilized for the VGRP (i.e., XXXXXXXXX) was applied to the CVGRP to determine if the same variables were still selected for the model. Six variables were selected after applying the variable selection technique.

CHAPTER V

Discussion

The purpose of this study was to empirically evaluate factors related to severity of concussion in order to create a prediction equation for RTP time. It is important to note that this is the first study to date that evaluated average RTP time based on factors that were previously associated with severity of concussion. A comprehensive review of the literature revealed numerous variables that have been associated with severity of concussion (i.e., RTP time) including raw score (e.g., 0-6) of 8 self-reported symptoms derived from the ImPACT PCSS (HA, NAU, DR, FOG, DC, DZ, STL, and STN), four neurocognitive composite scores (VERM, VISM, VMS, and RT) obtained via post-injury evaluation, and demographic variables (AGE, DBIT, and #CON). Upon further empirical analysis using XXXXXXXXX with XXXXX selection and XXXX stop criterion in SAS, the variables that were most closely related to RTP time were included in a XXXXXXXXX.

After reducing the number of variables, hypotheses one, three, and four were supported. The resulting equation significantly predicted average RTP time, demonstrating that the number of days out (i.e., severity) can be predicted by seven post-injury variables. Also, the predicted values for RTP time were highly correlated with observed RTP time, signifying that the results of the prediction equation accurately represented the observed number of days out. Finally, the regression equation was moderately stable across samples, indicating that the equation derived will provide similarly strong predictions when applied to other samples. Hypothesis two, that all variables included in the equation will provide unique contribution to RTP time, was not supported, suggesting that some variables were more related to RTP time than others.

The implications of hypothesis one are particularly encouraging. Primarily, the ability to predict RTP time using seven variables assessed at post-injury confirms that the post-injury concussion evaluation has prognostic value (the seven variables will be explored later in the discussion). This supports previous research and clinical judgment (Lovell et al., 2004a; Lovell et al., 2003) and reinforces the importance of a full concussion evaluation. Additionally, the ability to predict an average time out adds significant value to the presently available prognostic information. More specifically, instead of clinicians using cutoff groups (e.g., normal vs. protracted recovery) to guide the management of the injury, they now have a more accurate picture of the number of days an athlete may need to fully recover. Stated simply, once an athlete presents to a clinic for a concussion evaluation, the clinician can determine a predicted number of days out unique to that athlete using the equation derived in this study.

The ability to generate more accurate prognostic information has larger implications as well. Given the current recommendations on concussion management (McCrory et al., 2013), one group of athletes that needs to be managed more conservatively are those in middle school and high school. While clinicians tend to follow those recommendations by holding younger athletes out of play longer, in the sports world, every extra day of recovery time has clinical significance. For non-athletes an extra day or two of recovery may have less negative impact on their life. However, for athletes, missing an extra day may mean missing practice or a game. For example, the RTP protocol states an athlete must engage in heavy contact activity (e.g., full hitting practice in football) prior to being cleared for game activity. A common occurrence in high school football is to have a walk-through practice the day prior to the game. As such, in the case of a player cleared for heavy contact practice the day before the game, they often end up not able to play in the game because they were unable to participate in a full hitting practice.

Accordingly, having a better understanding of an athlete's RTP time after their initial post-injury evaluation can foster a more precise, individualistic management of the injury. For example, an athlete who is predicted to be out for 25 days may be managed more conservatively than an athlete who is predicted to be out for 14 days. The RTP decision is data driven, not based on retrospective information or grading scales. The ability to predict number of days out allows a clinician to be mindful of an athlete's needs while not compromising the athlete's safety.

The results of hypothesis three, that the predicted values for RTP time were highly correlated with observed RTP time, supplements the findings of hypothesis one. The ability to predict time out of play is extremely important (as previously discussed). However, knowing that RTP time can be *accurately* predicted lends even more support to the prediction equation. The accuracy of the prediction equation is demonstrated by the strength of the correlation between predicted RTP time and observed RTP time (r = .851). Cohen (1992) describes a correlation of this magnitude as having a large effect, as it indicates that 72.4% of the variance in RTP time is accounted for by the seven variables of the equation.

An accurate prediction equation has other implications as well. Primarily, accurately predicting RTP time can have an effect on the psychological component of injury recovery. Previous research has explored the psychological effect of injury on athletes who are withheld from competition, noting that athletes may suffer from mood disturbance and lower self-esteem (Smith, Scott, &Wiese, 1990). It may be inferred that much of the mood disturbance (e.g., anxiety, depression) can be due to missing out on sport participation and being with teammates. In the case of concussion, not only are athletes removed from play, but they are initially told to rest, sleep, and avoid any exertion (i.e., not going to practice even to watch). Additionally, the concussion also may result in fluctuating emotional states (e.g., sadness, irritability). Taken as a whole, the cumulative psychological effects of the concussion injury as well as the management of the injury can have a negative impact on an athlete’s psychological well-being. Unlike other injuries (e.g., a muscle strain which will keep one out for 2-4 weeks) athletes (especially younger athletes) who sustain a concussion are often not given a specific timeline for their return. The “unknown” of the recovery time may cause additional psychological distress and keep athletes from following their treatment plan as there may be “no end in sight.” Providing athletes with a more precise estimate of their recovery time can help to alleviate some of the stress related to the injury and help to motivate athletes to follow the recommended treatment plan.

Another potential implication of an accurate prediction equation is the research application. The ability to examine the effect of changes in the independent variables on the dependent variable can help researchers to better understand the nature of recovery from concussion. Stated simply, examining the coefficients provides information on which variables are most closely associated with largest changes in the DV. In the equation derived in this study, X had the greatest influence on RTP time. This supports previous research suggesting that X is a major component of concussion (Asplund et al., 2004; Mihalik et al., 2005). Understanding which variables are most closely associated with RTP time can help future researchers focus their efforts on creating more improved diagnostic and management guidelines.

The results of the fourth hypothesis, that the prediction equation was stable across samples, was supported by the moderate drop in Pearson correlation coefficients (r = .851 to r = .598). Additional support for the moderate stability of the equation across samples was found when the same variable selection technique (XXXXXXXXX) was applied to the CVGRP. Three of the original seven variables were stable across groups. This finding was especially important as it demonstrated the equation derived from the validation sample was able to produce similar results when applied to another sample. The implications of this finding are broad. The stability of the equation signifies that it can be applied to any population. It also implies that the variables derived from the XXXXXXXXX procedure hold true across samples and as such can be used to predict RTP across populations. Generally stated, any trained clinician who has information on the seven variables can utilize the prediction equation derived in this study.

Curiously, hypothesis two was not supported. That is, even after the number of variables was reduced to create the most parsimonious robust model, not every variable had a distinct statistically significant relationship with RTP. Only three had statistically significant contribution to RTP time. The significance of XX is clinically relevant as an athlete's symptomatology is likely to change the more time that has passed between their concussion and their evaluation. For example, the closer in time to when the injury occurred, the more symptomatic the athlete may be. Additionally, X has been consistently shown in the literature to be related to RTP time, and the results of this study support those findings (Asplund et al., 2004; Mihalik et al., 2005). As previously discussed, X has the largest β value, suggesting it has the largest influence on RTP time. Finally, XXX was shown to be significantly related to RTP time. It was important that one of the cognitive composite scores is related to RTP time, as cognitive functioning is an important part of the diagnostic and management process recommended by the ICCS (McCrory et al., 2013). Clinically, the significant relationship between XXX and the DV suggests that the effects of concussion compromise the brain's ability to do two things at once. Additionally, as previously discussed, XXX was one of the composite scores determined to be sensitive to processing speed changes based on external validation (Iverson, et al. 2005). This further supports why XXX would have been included in the model. Finding that three of the seven variables had a significant, distinct relationship with RTP time may help guide clinicians in the diagnosis and management of the injury. For example, during a post-injury evaluation, given these findings, clinicians can focus on values of the three to help generate a better picture of the severity of the injury.

Interestingly, while three of those variables included in the model have been found to be related to RTP time in the literature, in this study, they were determined to not be significantly related to RTP time individually. However, since they were included in the model after the model selection technique, it was found that, when bundled together, they still significantly contribute to the overall prediction of RTP time. The reason why each of three of the symptoms did not have a significant individual relationship with RTP time is likely due to XXXX. XXXX was an average of 8.18 days after injury and those symptoms may have remitted by then. Furthermore, XX was also determined to have a non-significant relationship with RTP time. This may be due to the limited variability of XX amongst the participants (mean XX = 16.3, SD = 1.67) as well as the XX-normed neurocognitive scores.

Limitations

While the study had many strong findings, there are a few potential limitations that may have affected the results. First, the sample was taken from an archival, clinical database. As such, the generalizability of the results may be limited. The influence of the diagnostic and management methods of the treatment providers as well as the clinic procedures cannot be ignored. For example, athletes were usually seen by the treatment team in one week intervals. Therefore, signs and symptoms of concussion may have remitted sooner, but the athlete was unable to be seen. Accordingly, RTP may have been artificially lengthened based on the workings of the clinic schedule. Additionally, it is possible that the clinical management guidelines that govern RTP in the sample put more emphasis on the seven variables included, not the eight that were excluded. Given that much of the existing research has been conducted using clinical databases, it is plausible that each team of clinicians weights variables slightly differently, hence the lack of consensus on which variables are most strongly associated with RTP time. However, given the strength of the results of this study, it is highly likely that each of the variables included in the model would have strong prognostic value across samples. Future research should attempt to take data from multiple clinical sites in order to create a more diverse clinical sample.

Furthermore, while a strong correlation between predicted RTP time and observed return to play time was demonstrated, the strength of the correlation may be due to the variable selection method, which helped to select the most parsimonious and robust model. As previously stated, the clinical nature of the sample may also have contributed to the strength of the correlation. That is, clinical RTP decision making likely included evaluation of a small, but frequently observed, number of variables. Therefore, there was not much remaining variance in RTP time to be accounted for as clinicians may have put a large emphasis on a small number of variables. As previously mentioned, selecting participants from different clinical samples in future research may provide further support for the variables selected.

Another limitation was the lack of variability of ages in the sample (mean AGE = 16.3, SD = 1.67) as the sample was mostly high school athletes (82.8%). As a result, the prediction model derived from the analyses may not be generalized to middle school, college, or professional athletes. Future studies could address this issue by exploring different prediction models for different ages as age has been considered a concussion modifier (McCrory et al., 2013).

Additionally, sample size may have negatively influenced the results. In order to create a prediction equation and test the stability of such equation, the sample was approximately split in half. Splitting the sample decreased the sample size of the VGRP (n = 139) on which the model was constructed. The result of this decrease in sample size might be the reason for the drop in correlation between predicted RTP time and actual RTP time (.851 to .598). Another limitation created by the sample size was the limited number of subjects-to-variable. The number of subjects-to-variable should usually be approximately 10-15; however the current study had 8.6 subjects per variable in the VGRP (including all 15 variables originally assessed).

In addition, the two significant differences between groups, STN and VISM, may have been due to the sample as well. However, while the *t*-tests were significant, the mean differences were not clinically significant (e.g., mean difference for STN = -.383; mean difference for VISM = -3.563). Increasing the overall sample size, or increasing the sample size of the VGRP may result in a more stable model and eliminate some or all of these limitations. Finally, the findings need to be replicated using double cross-validation techniques in order to further support the strength of the model. This approach will likely be maximally effective with a larger sample.

Implications and Future Research

As suggested in the most recent Consensus Statement on Concussion in Sport (McCrory et al., 2013), a range of “modifying” factors may influence prolonged recovery. However, McCory et al. (2013) also discussed the limited efficacy for these factors to date. Building upon their conclusions, the data driven model presented in this paper addresses this limited efficacy and adds much needed empirical support for concussion prognosis. Moreover, possessing a better understanding of recovery time could potentially have a positive effect on both athletes and clinicians. Some of these effects include reduced psychological distress relating to the “unknown” of how long recovery will take for the athlete, more accurate RTP recommendations (including academic and athletic accommodations), increased treatment adherence, and even potentially more support from parents, administrators, and athletic staff given that this prediction is data driven and not based on arbitrary estimates of severity (e.g., grading scales).

These results can be used to not only supplement the current research on sports-related concussion, but also as a basis for future studies. In order to create the most accurate prediction equation, future studies should use large sample sizes, samples with a larger age variability (e.g., potentially create prediction equations for specific age groups), and explore the inclusion of other predictors (e.g., gender). The equation derived can also be used in future studies that explore objective biomarkers in order to create the strongest, most valid prognostic indicators of concussion severity and time out of play. Finally, it is important to note that this model is not intended to be used as a sole diagnostic/prognostic tool, rather it is intended to be used to supplement diagnostic and prognostic decision making. It is important for treatment providers to utilize sound clinical judgment and not ignore the variables that were excluded from the model.

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Appendix

Post Concussion Symptom Scale

Symptom	None	Mild		Moderate		Severe	
Headache	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Balance Problems	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Trouble Falling Asleep	0	1	2	3	4	5	6
Sleeping More Than Usual	0	1	2	3	4	5	6
Sleep Less Than Usual	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Sensitivity to Light	0	1	2	3	4	5	6
Sensitivity to Noise	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervousness	0	1	2	3	4	5	6
Feeling More Emotional	0	1	2	3	4	5	6
Numbness or Tingling	0	1	2	3	4	5	6
Feeling Slowed Down	0	1	2	3	4	5	6
Feeling Mentally “Foggy”	0	1	2	3	4	5	6
Difficulty Concentrating	0	1	2	3	4	5	6
Difficulty Remembering	0	1	2	3	4	5	6
Visual Problems	0	1	2	3	4	5	6

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