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The Graduate School

College of the Liberal Arts

PREDICTORS OF POST-CONCUSSION SYMPTOMS

IN COLLEGIATE ATHLETES

A Thesis in

Psychology

by

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Abstract

In recent years, the sports community has been faced with the challenge of determining when it is safe to return concussed athletes to play. Given that return to play decisions revolve around athletes’ self-reported symptoms, it follows that having the ability to accurately predict the nature of post-concussion symptom reporting would greatly benefit the decision-making process. The purpose of the present study was to better characterize the symptoms athletes endorse, as well as to determine what impact pre-morbid and injury-specific characteristics have on the development and severity of post-concussion symptoms in the acute injury period following concussion. Participants were comprised of two groups of athletes including baseline participants (N=702) and post-concussion participants (N = 55). Athletes were administered a comprehensive battery of neuropsychological tests, consisting of both neurocognitive and neurobehavioral measures. The main outcome measure was the Post-Concussion Symptoms Scale (PCSS). A factor analysis was conducted on the participants’ baseline PCSS data to determine the factor structure of the PCSS. Four distinct symptom clusters emerged including cognitive, physical, affective, and sleep. Additionally, the Symptom Checklist 90-Revised symptom characterization framework (e.g., the “global indices of distress” variables) was applied to the PCSS, and descriptive statistics were reported. Finally, logistic regression analyses were conducted that examined the PCSS symptom clusters and global indices of distress variables, demographic/social variables, affective variables, neurocognitive variables, and injury-specific variables as predictors of dichotomized post-concussion PCSS total scores (e.g., low versus high symptom reporting). Results indicated that the physical and affective symptom clusters reliably predicted athletes’ post-concussion symptom group. Interestingly, physical symptoms were negatively associated with a high post-concussion symptom score while affective symptoms were positively associated with a high post-concussion symptom score. Additionally, the neurocognitive composite score significantly predicted athletes’ post-concussion symptom group in that those with higher cognitive scores at baseline were less likely to endorse high symptoms post-concussion. When all three significant predictors were analyzed together, the physical symptom cluster and neurocognitive composite score were most significantly associated with post-concussion symptom reporting. These findings suggest that future studies examining predictors of post-concussion symptoms are warranted.
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<th>Description</th>
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<tbody>
<tr>
<td>AAN</td>
<td>American Academy of Neurology</td>
</tr>
<tr>
<td>ADHD</td>
<td>Attention Deficit Hyperactivity Disorder</td>
</tr>
<tr>
<td>ATP</td>
<td>Adenosine Triphosphate</td>
</tr>
<tr>
<td>BDI-FS</td>
<td>Beck Depression Inventory-Fast Screen</td>
</tr>
<tr>
<td>BVMT-R</td>
<td>Brief Visuospatial Memory Test-Revised</td>
</tr>
<tr>
<td>CT</td>
<td>Computed Tomography</td>
</tr>
<tr>
<td>CTMT</td>
<td>Comprehensive Trail-Making Test</td>
</tr>
<tr>
<td>DTI</td>
<td>Diffusion Tensor Imaging</td>
</tr>
<tr>
<td>EFA</td>
<td>Exploratory Factor Analysis</td>
</tr>
<tr>
<td>fMRI</td>
<td>Functional Magnetic Resonance Imaging</td>
</tr>
<tr>
<td>GCS</td>
<td>Glasgow Coma Scale</td>
</tr>
<tr>
<td>GSI</td>
<td>Global Severity Index</td>
</tr>
<tr>
<td>HVLT-R</td>
<td>Hopkins Verbal Learning Test-Revised</td>
</tr>
<tr>
<td>ImPACT</td>
<td>Immediate Post-Concussion Assessment and Cognitive Testing</td>
</tr>
<tr>
<td>DMO</td>
<td>Kaiser-Meyer-Olkin</td>
</tr>
<tr>
<td>LOC</td>
<td>Loss of Consciousness</td>
</tr>
<tr>
<td>MRI</td>
<td>Magnetic Resonance Imaging</td>
</tr>
<tr>
<td>NEO-FFI</td>
<td>NEO-Five Factor Inventory</td>
</tr>
<tr>
<td>PC-PCSS-TS</td>
<td>Post-Concussion PCSS Total Score</td>
</tr>
<tr>
<td>PCSS</td>
<td>Post-Concussion Symptoms Scale</td>
</tr>
<tr>
<td>PCSS-GSI</td>
<td>Post-Concussion Symptoms Scale – Global Severity Index</td>
</tr>
<tr>
<td>PCSS-PSDI</td>
<td>Post-Concussion Symptoms Scale – Positive Symptom Distress Index</td>
</tr>
<tr>
<td>PCSS-PST</td>
<td>Post-Concussion Symptoms Scale – Positive Symptom Total</td>
</tr>
<tr>
<td>PSDI</td>
<td>Positive Symptom Distress Index</td>
</tr>
<tr>
<td>PST</td>
<td>Positive Symptom Total</td>
</tr>
<tr>
<td>PTA</td>
<td>Post-Traumatic Amnesia</td>
</tr>
<tr>
<td>SCL-90-R</td>
<td>Symptom Checklist-90-Revised</td>
</tr>
<tr>
<td>SCWT</td>
<td>Stroop Color-Word Test</td>
</tr>
<tr>
<td>SDMT</td>
<td>Symbol Digit Modalities Test</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for the Social Sciences</td>
</tr>
<tr>
<td>TBI</td>
<td>Traumatic Brain Injury</td>
</tr>
<tr>
<td>WAIS-III</td>
<td>Wechsler Adult Intelligence Scale-III</td>
</tr>
<tr>
<td>WTAR</td>
<td>Wechsler Test of Adult Reading</td>
</tr>
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Chapter 1. Introduction

General Overview of Sports-Related Concussion

Interest in sports-related concussion has intensified in recent years as a result of the increased awareness of the effects of such injuries. While the majority of sports-related concussions are considered “mild” brain injuries, physical, cognitive, and affective sequelae frequently develop after a concussion (Moser et al., 2007). Some of the more common symptoms that concussed athletes report include headache, dizziness, problems with attention and concentration, drowsiness, fatigue, feeling slowed down, and feeling mentally foggy (Lovell et al., 2006).

It is difficult to estimate the prevalence of sports-related concussion, as many go undetected or are not reported, but the Centers for Disease Control and Prevention suggests that 1.6 to 3.8 million sports-related concussions occur annually in the United States (Langlois, Rutland-Brown, & Wald, 2006). Proper management of concussions has therefore become an issue of importance in the sports community, and a key challenge has been developing appropriate guidelines for return to play. The current policy, developed by a consensus panel during the 3rd International Conference on Concussion in Sport, requires athletes to refrain from physical and cognitive exertion while they are experiencing post-concussion symptoms, and to return to play only after they are asymptomatic (McCrory et al., 2009). It follows, then, that being able to accurately predict the nature of athletes’ symptom reporting in the acute injury period following concussion may facilitate return to play decisions.

One method for predicting symptom reporting is to investigate whether there are any pre-morbid or pre-injury characteristics (e.g., “risk factors”) that influence athletes’ susceptibility to developing certain post-concussion symptoms. It is also possible that certain injury-specific...
factors may be related to the development of post-concussion symptoms. Very limited research, however, has been conducted on predictors of post-concussion symptoms. Identifying risk factors or injury-specific factors would, however, be extremely valuable, as the presence of post-concussion symptoms typically precludes return to play, and is likely indicative of ongoing brain dysfunction.

Concussion within the Context of Traumatic Brain Injury

Before focusing exclusively on sports-related concussions, it is important to understand where concussions fit within the context of traumatic brain injury (TBI). Traditionally, TBI’s have been viewed on a continuum according to injury severity. On one end of the continuum are the more “mild” injuries, and on the other end of the continuum are the more “severe” injuries. Injury severity is commonly determined by the following criteria: Glasgow Coma Scale (GCS; an instrument designed to evaluate eye opening, motor response, and verbal response); duration of post-traumatic amnesia (PTA); and duration of loss of consciousness (LOC). Typical classification criteria are listed in Table 1 (Iverson & Lange, 2011). By convention, concussive injuries are generally thought of as mild TBI’s, and although some efforts have been made to differentiate the term “concussion” from “mild TBI” (McCrory et al., 2009), the terms are frequently used interchangeably in the literature (Davis, Iverson, Guskiewicz, Ptito, & Johnston, 2009; Echemendia & Julian, 2001). “Concussion” appears to be the preferred term in the sports literature, however, and will thus be used hereafter.
### Table 1. Traumatic Brain Injury Classification Criteria

<table>
<thead>
<tr>
<th>Severity of Injury</th>
<th>GCS</th>
<th>PTA</th>
<th>LOC</th>
</tr>
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<tbody>
<tr>
<td>Mild</td>
<td>13-15</td>
<td>≤ 24 hours</td>
<td>&lt; 30 minutes</td>
</tr>
<tr>
<td>Moderate</td>
<td>9-12</td>
<td>&gt; 24 hours to 7 days</td>
<td>30 minutes to 24 hours</td>
</tr>
<tr>
<td>Severe</td>
<td>3-8</td>
<td>&gt; 7 days</td>
<td>&gt; 24 hours</td>
</tr>
</tbody>
</table>

*Concussion Definitions and Classification Systems*

While a universally accepted definition of concussion does not exist, commonly cited definitions share similar features—namely, that a concussion involves an element of trauma, accompanied by a change in mental status (American Academy of Neurology, 1997; Kelly et al., 1991; Kelly & Rosenberg, 1997; McCrory et al., 2009). The American Academy of Neurology’s (AAN) definition is frequently cited in the literature, and defines concussion as “a trauma-induced alteration in mental status that may or may not involve loss of consciousness” (American Academy of Neurology, 1997). Another widely cited definition, developed by panelists of the 3rd International Conference on Concussion in Sport, states, “Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces” (McCrory et al., 2009).

In addition to defining “concussion,” various classification systems, or grading scales, have also been developed to more accurately characterize injury severity within the framework of concussion. For example, the AAN’s grading scale proposes three injury severity classifications: Grade 1, which includes confusion, no loss of consciousness, and concussion symptoms that are present for less than 15 minutes; Grade 2, which includes confusion, no loss of consciousness, and concussion symptoms that are present for more than 15 minutes; and Grade 3, which includes a concussion involving any duration of loss of consciousness (American Academy of Neurology, 1997). Another commonly cited concussion classification system is the
Cantu Grading System. Originally proposed in 1986 (Cantu, 1986), this grading scale was updated in 2001 to account for advances in the sports-concussion literature (Cantu, 2001). According to the updated Cantu data-based grading scale, a Grade 1 concussion is considered “mild,” and involves “no loss of consciousness” and “posttraumatic amnesia or post-concussion signs or symptoms lasting less than 30 minutes;” a Grade 2 concussion is considered “moderate,” and involves “loss of consciousness lasting less than 1 minute” and “posttraumatic amnesia or post-concussion signs or symptoms lasting longer than 30 minutes but less than 24 hours;” and a Grade 3 concussion is considered “severe” and involves “loss of consciousness lasting more than 1 minute or post-traumatic amnesia lasting longer than 24 hours” and “post-concussion signs or symptoms lasting longer than 7 days” (Cantu, 2001). Additional concussion grading scales have been developed (Nelson, Jane, & Gieck, 1984; Roberts, 1992), but they appear to be utilized less frequently in the literature.

Biomechanics and Pathophysiology of Concussion

It has long been established that the direct or indirect application of force to the head—that which takes place during a concussion—leads to both mechanical and physiological disruptions within the brain (Gennarelli, 1986). Mechanically speaking, any changes that occur in the brain primarily depend on the circumstances surrounding the concussive injury (i.e., the mechanism of injury). Focal damage—meaning the damage is caused by a “direct blow” to the head and localized to a specific area of the brain, or diffuse damage—meaning the damage is caused by an abrupt movement of the head and spread throughout the whole brain, can result, or a combination of the two may ensue (Gennarelli, 1993; Guskiewicz & Mihalik, 2006; Ommaya & Gennarelli, 1974). It is well understood that the majority of sports-related concussions involve
linear and rotational acceleration forces that result in diffuse injuries (Guskiewicz & Mihalik, 2006; Meaney & Smith, 2011). Interestingly, linear acceleration forces have been associated with causing an increase in intracranial pressure, while rotational acceleration forces have been associated with tissue deformation (Meaney & Smith, 2011). However, despite these findings, it remains to be established how the types of acceleration forces are specifically related to symptom expression and severity, as well as and neurocognitive functioning.

In addition to the biomechanical changes that arise from concussion, physiological disruptions also occur. The pathophysiology of concussion has largely been studied using an animal model, and was well described in a seminal article by Giza and Hovda in 2001. Following cerebral concussion, cell membranes are disrupted and axonal stretching occurs as a result of the acceleration and deceleration forces that were applied to the brain at the time of injury. The resulting effect is the release of excitatory neurotransmitters such as glutamate, followed by the influx of calcium ions into the cell and the release of potassium ions out of the cell. Depolarization results, and the sodium-potassium pump is activated in order to reestablish “homeostasis” within the cell (e.g., reestablish the neuronal membrane potential). However, because the sodium-potassium pump requires large amounts of adenosine triphosphate (ATP) to remain active, glucose utilization is increased and hyperglycolysis results. Lactate production is also increased and accumulations are formed within the cell, resulting in neuronal dysfunction. At the same time, calcium ions are continuously entering the cell, and collections are formed within the mitochondria, ultimately resulting in an “energy failure” (e.g., oxidative dysfunction) through diminished production of ATP. During this process, cerebral blood flow is reduced and likely does not meet the required metabolic demand, leaving neurons vulnerable to further injury or potentially long-term damage. Finally, the drastic increase in glucose metabolism is
eventually followed by a decrease in glucose metabolism, and this period of decreased metabolism has been correlated with cognitive dysfunction in adult rats (Barkhoudarian, Hovda, & Giza, 2011; Giza & DiFiori, 2011; Giza & Hovda, 2001). Giza and Hovda (2001) referred to this entire process as the “neurometabolic cascade.”

Extensive animal research on the pathophysiology of concussion remains an area of active investigation, though over the past several years, more efforts are being placed on translational research. However, most of these endeavors have focused exclusively on patients with moderate or severe TBI (Bergsneider et al., 2000; Chamoun, Suki, Gopinath, Goodman, & Robertson, 2010; Timofeev et al., 2011; Vidgeon & Strong, 2011), and are therefore not necessarily applicable to sports-related concussions. Nevertheless, some investigators have concentrated on better delineating the mechanical and pathophysiological disturbances that result from sports-related concussion through advanced neuroimaging techniques such as diffusion tensor imaging (DTI) and functional magnetic resonance imaging (fMRI). These techniques will be briefly described in the latter part of the section that follows.

Assessment and Management of Sports-Related Concussion

The field of neuropsychology has been fundamentally involved in the assessment of sports-related concussion for years, and accordingly, neuropsychological testing has been considered the “cornerstone” of concussion management (Aubry et al., 2002). Neuropsychological assessment involves not only an evaluation of cognitive functioning, but also psychosocial functioning and neurobehavioral and psychiatric symptoms (Podell, Gifford, Bougakov, & Goldberg, 2010). These variables are typically assessed via self-report measures, questionnaires, paper-and-pencil tests, and computerized tests.
Originally developed by Barth and colleagues (1989), the “gold standard” of concussion management involves the administration of neuropsychological tests to athletes at baseline (ideally, prior to their participation in practice and games) in order to establish their “pre-injury performance level.” The neuropsychological test battery is designed to assess the cognitive domains that are frequently affected by concussion, such as memory, attention, processing speed, and reaction time (Ellemberg, Henry, Macciocchi, Guskiewicz, & Broglio, 2009; Moser et al., 2007), as well as symptoms that are commonly associated with concussion (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Macciocchi, Barth, Littlefield, & Cantu, 2001; Moser et al., 2007). The testing is then repeated on those athletes who sustain a concussion, and their post-injury scores are compared to their pre-injury scores to determine if there are changes in their cognitive performance or symptom profile (Barth et al., 1989; Echemendia et al., 2001; Moser et al., 2007). If, at one week post-concussion, athletes perform significantly below their baseline level of functioning on two or more tests on a typical sports concussion test battery, the assumption is that they are still experiencing difficulties as a result of their concussion, and the standing recommendation is to not allow them to return to play until more time has passed (Rosenbaum, Arnett, Bailey, & Echemendia, 2006). Similarly, if self-reported post-concussion symptoms persist, athletes are withheld from play until asymptomatic (Halstead & Walter, 2010; McCrory et al., 2009).

While the “gold standard” approach to concussion management has proven useful (Echemendia et al., 2001; Grindel, Lovell, & Collins, 2001; Van Kampen, Lovell, Pardini, Collins, & Fu, 2006), it has not gone without criticism. Randolph and Kirkwood (2009), for example, sought to determine whether the consequences of concussion are modifiable through concussion management strategies such as baseline neuropsychological testing. They argued that
while there may be a role for neuropsychological testing in situations involving an unusual or delayed recovery following concussion, routine baseline testing is not warranted, as it contributes little to improving short-term outcomes following concussion (Randolph & Kirkwood, 2009). Other studies have criticized the incremental validity of baseline neuropsychological testing, as well as the psychometric properties of the testing instruments, ultimately concluding that there is insufficient evidence to support the routine use or clinical application of baseline neuropsychological testing (Kirkwood, Randolph, & Yeates, 2009; Randolph, 2011; Randolph, McCrea, & Barr, 2005). Despite these criticisms, however, baseline and post-concussion neuropsychological testing is widely used in high school (Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Moser, Schatz, & Jordan, 2005), collegiate (Bailey, Echemendia, & Arnett, 2006; Echemendia et al., 2001; McCrea et al., 2003) and professional (Pellman, Lovell, Viano, Casson, & Tucker, 2004; Solomon & Haase, 2008) athletics in an effort to manage concussions.

In addition to neuropsychological testing, both structural and functional neuroimaging modalities have also been utilized to aid in the assessment of concussion. With respect to structural neuroimaging, computed tomography (CT) and magnetic resonance imaging (MRI) appear to be the most widely used techniques. While both CT and MRI are capable of identifying gross anatomical (structural) changes in the brain such as fractures or contusions, MRI scans are more sensitive to the subtle structural changes that may occur in the brain following concussion (for a review, see Bazarian, Blyth, & Cimello, 2006; Ellemberg et al., 2009). Nevertheless, research has shown that the majority of concussions do not result in structural abnormalities that are visible on CT or MRI (Bigler, 2010; Cubon, Putukian, Boyer, & Dettwiler, 2011; Ellemberg et al., 2009; Pulsipher, Campbell, Thoma, & King, 2011). For this
reason, within the sports-concussion world, CT and MRI are typically not conducted on athletes unless intracranial abnormalities are suspected (McCrory et al., 2009; Pulsipher et al., 2011).

Diffusion tensor imaging (DTI), a more advanced structural imaging procedure, has also been utilized in the assessment of concussion. While only a limited number of DTI studies have focused on sports-related concussion, promising findings have resulted. Recently, Cubon and colleagues (2011) sought to determine whether DTI is capable of detecting white matter abnormalities in a group of concussed collegiate athletes who experienced persisting post-concussion symptoms (e.g., symptoms lasting longer than one month post-injury). The authors concluded that DTI is indeed sensitive to the subtle structural changes that appear in the white matter tracts of athletes’ concussed brains, and strongly advocated the use of DTI to assess sports-related concussions (Cubon et al., 2011). Similar DTI findings have also been reported in both the civilian (Messé et al., 2011; Niogi & Mukherjee, 2010) and military (Mac Donald et al., 2011) mild TBI populations.

In contrast to structural neuroimaging, functional neuroimaging allows for a better understanding of the pathophysiological consequences of concussion (Bigler, 2010; Munson, Schroth, & Ernst, 2006). Furthermore, functional imaging techniques have proven to be beneficial in that they are capable of detecting abnormalities that are not evident on structural neuroimaging (for a review, see Jantzen, 2010; Ptito, Chen, & Johnston, 2007). A number of studies have used fMRI to investigate neuropsychological functioning and symptom reporting in concussed athletes. The majority of these studies utilized various working memory tasks, and several investigators reported atypical task-related activation in the dorsolateral prefrontal cortex of concussed athletes as compared to control subjects (Chen et al., 2004; Chen, Johnston, Collie, McCrory, & Ptito, 2007; Chen, Johnston, Petrides, & Ptito, 2008a, 2008b; Jantzen, Anderson,
Steinberg, & Kelso, 2004; Lovell et al., 2007). However, differential patterns of activation were documented across these studies. Thus, while fMRI appears to be a sensitive technique for detecting change following concussion, more studies will need to be conducted before fMRI will be recommended for routine use in the clinical setting.

Consequences of Concussion

The nature and course of recovery following sports-related concussion has been studied extensively over the past decade. While there is some evidence to suggest that the majority of concussed athletes return to baseline levels of functioning and experience symptom resolution within one week post-injury (Belanger & Vanderploeg, 2005; Echemendia et al., 2001; Lovell et al., 2004; McCrea et al., 2003), other work suggests that neurocognitive deficits and post-concussion symptoms last up to two weeks or even longer in some athletes (McClincy, Lovell, Pardini, Collins, & Spore, 2006; Meehan III, d’Hemecourt, & Comstock, 2010). The literature also suggests that recovery rates from concussion may vary depending upon age or level of participation (i.e., professional, collegiate, or high school). Pellman and colleagues (2006), for instance, sought to determine whether neuropsychological recovery rates differ in professional athletes as compared to high school athletes. The authors administered the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) battery, which includes an evaluation of cognitive domains such as verbal and visual memory, processing speed, and reaction time, as well as a symptom inventory, to professional and high school football players, and discovered that recovery rates do differ between the two groups. Whereas professional athletes recovered within one week post-injury, high school athletes continued to experience neuropsychological deficits lasting longer than one week post-injury (Pellman, Lovell, Viano, & Casson, 2006).
Similarly, other studies have shown that collegiate athletes recover more quickly than high school athletes on measures of neuropsychological functioning (Covassin, Elbin, Harris, Parker, & Kontos, 2012; Field, Collins, Lovell, & Maroon, 2003).

Researchers have also investigated whether the course of recovery can be predicted based on an athlete’s symptom presentation and neurocognitive profile post-concussion (Iverson, 2007; Lau, Collins, & Lovell, 2012; Lau, Lovell, Collins, & Pardini, 2009). For example, Lau et al. (2009) conducted a study to determine whether specific symptoms or neurocognitive patterns assessed approximately two days post-injury could predict recovery in a sample of concussed high school football players. Participants were administered the ImPACT battery and a 22-item symptom inventory, and were followed until their neurocognitive deficits and symptoms disappeared. Lau and colleagues found that athletes who took 10 days or more to recover reported greater symptom scores on the symptom inventory, and had worse Visual Memory and Processing Speed composite scores on the ImPACT at two days post-concussion, compared to athletes who recovered before 10 days (Lau et al., 2009). While these results suggest that both symptom reporting and neurocognitive test results are predictive of outcome, additional studies will need to be conducted in order to determine the extent to which recovery rates from sports-concussion can be predicted.

Return to Play

Questions concerning return to play decisions are widespread, and occur at all levels of sports participation. Thus, it comes as no surprise that the sports community has been challenged by developing appropriate guidelines for return to play. As mentioned previously, the current policy, established during the 3rd International Conference on Concussion in Sport in
2008, requires athletes to refrain from physical and cognitive exertion until asymptomatic (McCrory et al., 2009). The philosophy behind this requirement is that it is believed that cognitive tasks such as concentrating and paying attention may exacerbate symptoms, and possibly affect recovery rates (Halstead & Walter, 2010). Following resolution of all post-concussion symptoms while at rest, athletes are directed to participate in a “graduated return to play protocol” which involves the following steps: light aerobic exercise, sport-specific exercise, non-contact training drills, full contact practice, and finally, return to play (McCrory et al., 2009). Athletes are allowed to advance to the next level of the protocol only after remaining asymptomatic for 24 hours at their current level of participation. If symptoms reappear at any point during the return to play protocol, athletes must return to the previous level at which they were asymptomatic.

Previous Research on Predictors of Post-Concussion Symptoms

It is evident that research related to sports-concussion is very extensive, covering a broad range of topics from biomechanics of the injury to outcome. However, despite these widespread efforts, limited research has focused on the impact that pre-morbid or injury-specific characteristics may have on post-concussion symptom reporting. Identifying specific “risk factors” that are predictive of post-concussion symptom reporting would be extremely valuable because the presence of post-concussion symptoms precludes return to play, and is likely suggestive of ongoing brain dysfunction. Furthermore, this knowledge would allow team physicians and athletic trainers to provide more realistic expectations to athletes regarding their return to play status.
While there appears to be limited research on pre-morbid and pre-injury predictors of post-concussion symptoms in the acute injury period following concussion, gender may be a possible predictor. Broshek and colleagues (2005) compared male and female athletes, and reported that females experienced greater neurocognitive declines and reported a greater number of symptoms than males in the acute injury period following sports-related concussions. While other studies have drawn similar conclusions (Covassin et al., 2012; Farace & Alves, 2000; Preiss-Farzanegan, Chapman, Wong, Wu, & Bazarian, 2009), the finding that females endorse more symptoms than males is not consistent across all studies. Covassin et al. (2007) explored gender differences in post-concussion symptom reporting and found that, overall, there were no differences in total symptom score between males and females. However, when looking at individual symptoms, males were more likely than females to endorse specific symptoms such as “sadness” and “vomiting” (Covassin et al., 2007). Similarly, Frommer et al. (2011) found no differences in total symptom score between males and females, but reported differences between the genders with respect to the type of symptoms endorsed. Specifically, males were more likely to endorse “amnesia” and “confusion/disorientation,” whereas females were more likely to endorse “drowsiness” and “sensitivity to noise.”

In addition to gender differences, there is some evidence to support the notion that a history of concussion will result in increased symptom reporting following a subsequent concussion (Collins et al., 2002; Guskiewicz et al., 2003; Moser et al., 2005). Yet, other studies have demonstrated that a history of concussion has no effect on symptom reporting for later concussions (Collie, McCrory, & Makdissi, 2006; Covassin, Stearne, & Elbin III, 2008; Iverson, Brooks, Collins, & Lovell, 2006). These incongruent results may best be explained by the fact that studies define having a “history of concussion” differently—some studies classify
concussion history in a bivariate fashion (i.e., yes or no) while other studies classify concussion history as a continuous variable (i.e., 0 previous concussions versus 1, 2, or 3 or more past concussions). Hence, further investigation into the effects of previous concussions seems warranted.

With respect to affective predictors of post-concussion symptom reporting, Cicerone & Kalmar (1997) explored whether pre-morbid depression influenced post-concussion symptom reporting, and found no differences in symptom reporting between those with and without pre-morbid depression. Similarly, researchers have investigated whether personality traits play a role in post-concussion symptom reporting (Garden, Sullivan, & Lange, 2010; Ruff, Camenzuli, & Mueller, 1996), but no clear predictors have been established. Personality assessments such as the NEO-Five Factor Inventory (NEO-FFI) have also been used in the sports literature to determine whether personality factors are predictive of “high-risk behavior” such as soccer heading (Webbe & Ochs, 2007), and another study used the NEO-FFI to predict coping behavior in athletes (Allen, Greenlees, & Jones, 2011). Since the NEO-FFI has been utilized to predict a variety of events in the sports literature, it may also prove to be a valuable predictor of post-concussion symptoms, and is therefore worth exploring.

Few studies have also examined injury-specific predictors of post-concussion symptoms. Collins et al. (2003) examined the influence of injury-specific variables (loss of consciousness, retrograde and anterograde amnesia, and presence of disorientation) on neurocognitive performance and symptom reporting in a sample of 78 high school athletes who had sustained concussions. The authors divided the sample into two groups based on “good post-injury presentation” (those with no change in memory and symptom reporting from baseline to post-concussion) and “poor post-injury presentation” (those with at least a 10-point decrease in
memory functioning and at least a 10-point increase in symptom reporting). Collins and colleagues found no differences between good and poor presentation groups with respect to loss of consciousness and disorientation, but reported that athletes who demonstrated poor presentation were 10 times more likely to have exhibited retrograde amnesia, and four times more likely to have exhibited anterograde amnesia at the time of injury. Another study sought to determine whether on-field signs and symptoms such as loss of consciousness, retrograde and posttraumatic amnesia, and dizziness were predictive of rapid (defined as less than or equal to seven days post-injury) or protracted (defined as greater than or equal to 21 days post-injury) recovery (Lau, Kontos, Collins, Mucha, & Lovell, 2011). The authors found that dizziness at the time of injury was the only variable that was predictive of a protracted recovery. Given these limited findings, it seems worthwhile to further explore the extent to which injury-specific factors affect post-concussion symptom reporting.

Finally, in addition to searching for “risk factors” that influence symptom reporting, there is also a need to better characterize the symptoms athletes endorse. In the sports literature, the Post-Concussion Symptoms Scale (PCSS) is often used to assess symptom severity, but the PCSS total score is typically the only dependent variable that is evaluated (Lovell et al., 2006). Unfortunately, this approach does not allow for an understanding of the total number of symptoms endorsed, nor does it allow for an understanding of the severity of each symptom. Put simply, the nature of athletes’ symptom reporting patterns is unclear. Specifically, a PCSS total score of 22 could be obtained in a number of ways. For instance, one athlete could report severity ratings of “1” for every symptom listed on the PCSS, while another athlete could endorse only four of the 22 symptoms, rating two symptoms as “5’s” and two symptoms as “6’s.” In this example, both athletes end up with the same PCSS total score, but the pattern of
their reporting is vastly different, implying that they may have sustained two very different injuries.

In order to better characterize symptoms, it is possible that the symptom framework of the Symptom Checklist 90-Revised (SCL-90-R) could be applied to the PCSS. The SCL-90-R is a widely used self-report measure that was designed to not only assess symptoms of psychopathology, but also to provide a summary of patients’ symptoms, both in terms of the number and intensity of endorsed symptoms (Derogatis, 1994). The measure is made up of nine primary symptom dimensions, as well as three “global indices of distress,” including the Global Severity Index (GSI), the Positive Symptom Total (PST), and the Positive Symptom Distress Index (PSDI). The GSI takes into account the number of symptoms endorsed, as well as the severity of each symptom; the PST is a count of the total number of symptoms endorsed; and the PSDI is considered an intensity measure that is corrected for the number of endorsed symptoms. Applying the SCL-90-R symptom characterization framework (e.g., the global indices of distress) to the PCSS may allow for a better understanding of athletes’ symptoms, as well as the ability to make more fine-grained predictions regarding symptom reporting.

**Present Study**

With the above considerations in mind, the purpose of the present study was to better characterize the symptoms athletes endorse, as well as to determine what impact pre-morbid and injury-specific characteristics have on the development and severity of post-concussion symptoms in the acute injury period following concussion. The specific aims and hypotheses of the study are outlined below.
Specific Aim 1: Conduct a factor analysis to determine the factor structure of the Post-Concussion Symptoms Scale (PCSS). Hypothesis: A factor analysis was previously conducted on post-concussion PCSS data, and the following symptom clusters were established: cognitive, sleep, emotionality, and somatic (Pardini et al., 2004). Based on these results, it was hypothesized that the factor structure of the baseline PCSS would reveal four distinct symptom clusters.

Specific Aim 2: Apply the SCL-90-R framework (the “global indices of distress”) to the PCSS in order to better characterize athletes’ symptom profiles. Hypothesis: This aim is exploratory, and therefore a specific hypothesis was not generated.

Specific Aim 3: Identify pre-morbid/pre-injury characteristics that are predictive of post-concussion symptom reporting in the acute injury period. Hypothesis: It was hypothesized that the following pre-morbid characteristics would be predictive of an increased total symptom score post-concussion: gender, concussion history, and the neuroticism personality factor. In addition to investigating the above hypothesis, the predictability of other pre-morbid and pre-injury variables was explored, including the PCSS variables at baseline derived from Specific Aims 1 and 2, demographic/social variables, affective variables, and neurocognitive variables. However, due to the lack of prior research examining these variables, the examination of the latter relationships was exploratory in nature.

Specific Aim 4: Identify injury-specific characteristics that are predictive of post-concussion symptom reporting in the acute injury period. Hypothesis: It was hypothesized that the presence of retrograde and anterograde amnesia will be predictive of an increased total symptom score post-concussion. Loss of consciousness was also explored, but the relationship between loss of consciousness and the post-concussion symptom score was exploratory.
Specific Aim 5: Using results from Specific Aims 3 and 4, determine the best predictors of symptom reporting in the acute injury period. Hypothesis: This aim was exploratory, and therefore a specific hypothesis was not generated.
Chapter 2. Methods

Participants

Participants included male and female college athletes who were involved in an ongoing concussion management program at a large university. All athletes participating in the program were administered baseline neuropsychological tests prior to their participation in varsity athletics. The concussion management program was modeled after the Sports as a Laboratory Assessment Model developed by Barth and colleagues (Barth et al., 1989). The following varsity athletic teams participated in baseline testing: Football, Wrestling, Men’s and Women’s Basketball, Men’s and Women’s Lacrosse, Men’s and Women’s Soccer, and Men’s and Women’s Ice Hockey. When athletes sustain a concussion, as defined by the Cantu data-based grading scale (defined above), they are referred for post-concussion testing, which takes place as soon as possible after the injury.

Participants were comprised of two groups—baseline participants and post-concussion participants. At the time of data analysis, baseline participants were selected from a sample consisting of 799 athletes and were included in the study if (1) they had completed the Post-Concussion Symptoms Scale (PCSS) measure (88.24% of the original sample) and (2) the PCSS total score was not considered an outlier, defined as being greater than 5 standard deviations above the mean (87.86% of the original sample). The final baseline sample consisted of 702 male and female college athletes (age at baseline: M = 18.44, SD = 0.93). Additional sample characteristics for baseline participants are presented in Table 2. From this sample, eighty participants went on to sustain a concussion and were included in the study if (1) the mechanism of injury was due to a sports-related event (87.50% of the concussed sample) and (2) the athletes were tested within one week post-injury (168 hours; 68.75% of the concussed sample). The final
post-concussion sample consisted of 55 male and female athletes (age at baseline: M = 18.33, SD = 0.64), and the average time tested post-injury was 61 hours (SD=33.59). Sample characteristics for post-concussion participants are presented in Table 3.

Given that previous studies investigating pre-morbid predictors of post-concussion symptoms have reported medium to large effect sizes (Broshek et al., 2005; Farace & Alves, 2000; Garden et al., 2010), an a priori power analysis was conducted to determine the number of subjects that would be needed to obtain similar effects. The power analysis revealed that a minimum of 53 concussed athletes would be needed to detect a medium-large effect size (Cohen, 1992; Green, 1991) with 80% power at the 0.05 significance level.
### Table 2. Baseline Sample Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number</th>
<th>Percent</th>
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<tr>
<td>Gender</td>
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<tr>
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<tr>
<td>Female</td>
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<td>2 or more</td>
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<tr>
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</tr>
<tr>
<td>Men’s Ice Hockey</td>
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<td>7.6</td>
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<tr>
<td>Men’s Lacrosse</td>
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<td>Women’s Soccer</td>
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<tr>
<td>Other</td>
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</table>

*Note: N = 702.*

### Table 3. Post-Concussion Sample Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number</th>
<th>Percent</th>
</tr>
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<td>Gender</td>
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<tr>
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<td>Ethnicity</td>
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<td>Caucasian</td>
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<tr>
<td>African American</td>
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<td>32.7</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>10.9</td>
</tr>
<tr>
<td>Concussion History</td>
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<tr>
<td>0</td>
<td>28</td>
<td>50.9</td>
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<tr>
<td>1</td>
<td>16</td>
<td>29.1</td>
</tr>
<tr>
<td>2 or more</td>
<td>11</td>
<td>20.0</td>
</tr>
<tr>
<td>Diagnosis of Developmental Disorder</td>
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<td></td>
</tr>
<tr>
<td>Yes</td>
<td>11</td>
<td>20.0</td>
</tr>
<tr>
<td>No</td>
<td>44</td>
<td>80.0</td>
</tr>
<tr>
<td>Sport</td>
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<td></td>
</tr>
<tr>
<td>Football</td>
<td>28</td>
<td>50.9</td>
</tr>
<tr>
<td>Men’s Basketball</td>
<td>5</td>
<td>9.1</td>
</tr>
<tr>
<td>Men’s Ice Hockey</td>
<td>2</td>
<td>3.6</td>
</tr>
<tr>
<td>Men’s Lacrosse</td>
<td>10</td>
<td>18.2</td>
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<tr>
<td>Men’s Soccer</td>
<td>2</td>
<td>3.6</td>
</tr>
<tr>
<td>Women’s Basketball</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>Women’s Ice Hockey</td>
<td>3</td>
<td>5.5</td>
</tr>
<tr>
<td>Women’s Lacrosse</td>
<td>4</td>
<td>7.3</td>
</tr>
</tbody>
</table>

*Note: N = 55.*
Procedure

All participants were administered a neuropsychological test battery at baseline. The test battery consisted of both neurocognitive and neurobehavioral measures (described below). Athletes who subsequently sustained a concussion were referred for testing by one of the team physicians and administered a similar battery of tests post-concussion, using alternate forms when available. Some athletes were tested on more than one occasion following their injury, depending on the results of their first post-concussion evaluation. For the purpose of the present study, however, only the first post-concussion evaluation was considered. The neuropsychological measures were administered by graduate students and undergraduate research assistants, under the supervision of a Ph.D.-level clinical neuropsychologist. Baseline and post-concussion testing sessions took approximately 1.5 hours to complete, and additional time (approximately 30 minutes) was required to complete paperwork and the administration of other instruments not included in the present study. The university’s Institutional Review Board approved the study, and informed consent was obtained for all participants.

Measures

Participants were administered a comprehensive battery of neuropsychological tests, consisting of both neurocognitive and neurobehavioral measures. These measures are described below in detail.

Neurocognitive Measures:

The neurocognitive test battery was made up of measures designed to assess a variety of cognitive domains including memory, attention, and executive functioning. The measures
included: the Brief Visuospatial Memory Test-Revised (Benedict, 1997), the Hopkins Verbal Learning Test-Revised (Brandt & Benedict, 2001), the Digit Span Test (Wechsler, 1997), the Symbol-Digit Modalities Test (Smith, 1991), the Comprehensive Trail-Making Test (Reynolds, 2002), the PSU Cancellation Task (Echemendia & Julian, 2001), the Vigil/W Continuous Performance Test (Cegalis & Cegalis, 1994), and the Stroop Color-Word Test (Trenerry, Crosson, DeBoe, & Leber, 1989). Additionally, the ImPACT (Lovell, Collins, Podell, Powell, & Maroon, 2000) and the Wechsler Test of Adult Reading (The Psychological Corporation, 2001) were administered.

**Brief Visuospatial Memory Test-Revised (BVMT-R).** The BVMT-R is a test of visual memory (Benedict, 1997). Examinees are presented with a display of six geometric figures for 10 seconds, and after the display has been removed, they are asked to draw the figures as accurately as possible, and in the same location, on a blank piece of paper. After the first display, there are two additional learning trials, and then a delayed recall trial is administered 25 minutes after the third learning trial. The test has six alternate forms. The BVMT-R has been shown to have high reliability (Benedict, 1997) and validity (Benedict, Schretlen, Groninger, Dobraski, & Shpritz, 1996).

**Hopkins Verbal Learning Test-Revised (HVLT-R).** The HVLT-R is a measure of verbal learning and memory (Brandt & Benedict, 2001). Examinees are read a list of 12 words and are then asked to repeat as many words as they can, in any order, from the list. The HVLT-R comprises three learning trials, followed by a delayed recall trial about 20-25 minutes after the third learning trial. Finally, a delayed recognition trial is administered. The test has six alternate forms. The reliability and validity of the HVLT-R has been adequately demonstrated (Benedict, Schretlen, Groninger, & Brandt, 1998; Brandt & Benedict, 2001; Shapiro, Benedict, Schretlen, &
Brandt, 1999), and the test has been shown to be useful in the assessment of closed head injury (Bruce & Echemendia, 2003).

**Digit Span Test.** The Digit Span Test is a subtest of the Wechsler Adult Intelligence Scale-III (WAIS-III), and was designed to measure working memory and attention (Wechsler, 1997). The Digit Span Test is made up of Digits Forward and Digits Backward. During Digits Forward, examinees are read a series of numbers at a rate of one per second, and are asked to repeat the number sequence in the same order as it was presented. Digits Forward is a simple auditory test of attention. During Digits Backward, examinees are read a series of numbers, and are asked to repeat the number sequence in the reverse order. Digits Backward is an auditory measure of complex attention and working memory. The Digit Span Test has been shown to have adequate reliability and validity (The Psychological Corporation, 1997).

**Symbol-Digit Modalities Test (SDMT).** The SDMT is a measure of memory, attention, and motor speed (Smith, 1991). Examinees are presented with a display containing a series of symbols, and a coding key at the top of the display with nine symbol-number pairs. Examinees are given 90 seconds to pair the symbols within the display with the corresponding number, according to the coding key. Examinees are asked to record their answers as quickly as possible. The SDMT has been demonstrated to have high reliability (Strauss, Sherman, & Spreen, 2006) and validity (Ponsford & Kinsella, 1992), and the test has been shown to be effective in assessing recovery following brain injury (Felmingham, Baguley, & Green, 2004; Smith, 1991).

**Comprehensive Trail-Making Test (CTMT).** The CTMT is a measure of attention, as well as mental flexibility and visual-motor speed (Reynolds, 2002). The overall goal of the test is to connect numbers and/or letters that are printed on a page in a particular order as quickly as possible. The CTMT comprises five unique trials, and Trails 2-5 have been selected for use
within the concussion test battery. Trail 5, for example, contains numbers 1-13 and letters A-L, and examinees are asked to draw a consecutive line, starting with number 1, and alternating between numbers and letters (i.e., 1, A, 2, B, 3, C, etc.) through 13. The other trails (Trails 2-4) contain either Arabic numerals (e.g., 1, 2, 3, etc.) or numbers printed in word form (e.g., one, two, three, etc.), but no letters. The CTMT has been found to have high reliability and validity (Gray, 2006).

**PSU Cancellation Task.** The PSU Cancellation Task is a measure of attention and visual scanning (Echemendia & Julian, 2001). Examinees are presented with a display containing many symbols, and a target symbol at the top of the display. Examinees are asked to draw a line through each symbol in the display that is identical to the target symbol, and are directed to work as quickly as possible. Ninety seconds are allotted for this task. The PSU Cancellation Task has been used previously in the assessment of sports-related concussion (Echemendia & Julian, 2001; Echemendia et al., 2001; Rabinowitz & Arnett, 2012).

**Vigil/W Continuous Performance Test.** The Vigil is a computerized test designed to measure attention, concentration, and reaction time (Cegalis & Cegalis, 1994). During this task, a series of letters flash on a computer screen one at a time, and examinees are directed to hit the space bar as quickly as possible each time the letter “K” appears. The Vigil has been previously used in the assessment of sports-related concussion (Bailey et al., 2006; Echemendia & Julian, 2001; Echemendia et al., 2001).

**Stroop Color-Word Test (SCWT).** The SCWT is made up of two trials that are designed to measure executive function, specifically components such as processing speed, response inhibition, and response shifting (Trenerry et al., 1989). In both trials, examinees are presented with a stimulus sheet that contains 112 color-words (e.g., blue, green, red, and tan). Each color-
word is printed in a non-matching color (for example, the word “red” is printed in blue ink). During the first trial (SCWT-Word Task), examinees are asked to read the words aloud as quickly as possible. During the second trial (SCWT-Color/Word Task), examinees are asked to name the printed color of the word as quickly as possible. The SCWT has been shown to have adequate reliability and validity (Strauss et al., 2006; Tretherapy et al., 1989).

**Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).** The ImPACT is a computerized test that was designed specifically for use in the assessment and management of sports-related concussions (Lovell et al., 2000). The test contains six modules that assess the following cognitive domains: attention, memory, working memory, visual scanning, reaction time, and processing speed. Five composite scores can be derived from the modules: Verbal Memory, Visual Memory, Reaction Time, Processing Speed, and Impulse Control. Additionally, information pertaining to demographics, medical history, and current symptoms are also collected. (For more information about the symptom inventory, see the “Neurobehavioral Measures” section below). ImPACT is a widely used measure in the sports-concussion literature (Iverson, 2011; Lau, Collins, & Lovell, 2011; Rabinowitz & Arnett, 2012), and its sensitivity to the acute effects of concussion has been broadly established (Lovell et al., 2003; Schatz, 2010; Schatz, Pardini, Lovell, Collins, & Podell, 2006; Van Kampen et al., 2006).

**Wechsler Test of Adult Reading (WTAR).** The WTAR is a reading recognition test that was designed for the purpose of estimating premorbid intellectual function (The Psychological Corporation, 2001). The WTAR contains 50 irregularly spelled words (e.g., ballet), and examinees are asked to pronounce each word aloud. Reading recognition is thought to be relatively resistant to cognitive deficits that result from brain injury, and therefore the WTAR is considered a reasonable indicator of premorbid ability. The WTAR was co-normed with the
WAIS-III, and is highly correlated with the WAIS-III Full Scale IQ score (The Psychological Corporation, 2001). Furthermore, the WTAR has been shown to have high test-retest reliability, as well as high convergent validity (The Psychological Corporation, 2001), and has been used to measure premorbid cognitive ability in concussion (Rabinowitz & Arnett, 2012).

**Neurobehavioral Measures:**

**Post-Concussion Symptoms Scale (PCSS).** The PCSS is a self-report measure that was designed to assess the severity of concussion-related symptoms. The PCSS is administered on the computer through the ImPACT program. The selection of symptoms for the PCSS was based on symptom reports gathered from professional and amateur athletes (Lovell et al., 2006). Since the development of the PCSS, several variations of the scale have been created and utilized in the concussion literature (Eyres, Carey, Gilworth, Neumann, & Tennant, 2005; Meterko et al., 2012; Randolph et al., 2009; Van Dyke, Axelrod, & Schutte, 2010), but the PCSS appears to be the most widely used symptom assessment. Lovell et al. (2006) reported that the PCSS is a highly reliable measure, with an internal consistency between 0.89-0.94.

**Beck Depression Inventory – Fast Screen (BDI-FS).** The BDI-FS (Beck, Steer, & Brown, 2000) is a self-report measure of depression that was modeled after the original Beck Depression Inventory. The BDI-FS contains 7 statements, each corresponding to a particular symptom, and the statements are rated on a 4-point scale ranging from 0 to 3. The numerical responses to each statement are summed to provide an overall score of depression. Higher scores indicate greater depression. The BDI-FS symptoms include: sadness, pessimism, failure, anhedonia, self-dislike, self-blame, and suicidal ideation. The BDI-FS has been used with both
healthy and clinical populations, and is reliable and well-validated (Beck et al., 2000; Benedict, Fishman, McClellan, Bakshi, & Weinstock-Guttman, 2003; Poole, Bramwell, & Murphy, 2009).

**NEO-Five Factory Inventory (NEO-FFI).** The NEO-FFI is a 60-item self-report measure containing statements designed to assess the following personality dimensions: Extraversion, Neuroticism, Openness, Agreeableness, and Conscientiousness (Costa Jr & McCrae, 1992). Each item is rated using a 5-point Likert scale, with 1 indicating “strongly disagree,” 3 indicating “neutral,” and 5 indicating “strongly agree.” The NEO-FFI has been utilized in the sports literature to assess personality (Allen et al., 2011; Webbe & Ochs, 2007), and has demonstrated sufficient reliability and validity (McCrae & Costa, 2004).

**Approach to Data Analysis**

All analyses were conducted with the Statistical Package for the Social Sciences (SPSS), Version 19.0 (IBM Corp., 2010), and significance levels were set at .05.

**Specific Aim 1: Conduct a factor analysis to determine the factor structure of the PCSS.**

An Exploratory Factor Analysis (EFA) was performed on the 22 items that comprise the PCSS. Only baseline data from athletes who had complete PCSS questionnaires were included in the analysis. Factors were extracted using Principal Components Analysis, and Varimax (orthogonal) rotation with Kaiser normalization was utilized. It was determined a priori that individual symptoms with rotated component loadings greater than 0.4 would be retained in the final factor solution. If an item cross-loaded (>0.4) on two or more factors, the item was assigned to the factor with the largest loading. Finally, in order to verify the internal consistency of the retained factors, Cronbach’s α was utilized.
Specific Aim 2: Apply the SCL-90-R framework (the “global indices of distress”) to the PCSS in order to better characterize athletes’ symptom profiles.

Individual responses on the baseline PCSS were first transformed into the following SCL-90-R global indices of distress variables: Global Severity Index (GSI), Positive Symptom Total (PST), and Positive Symptom Distress Index (PSDI). The GSI was calculated by dividing the PCSS total score by 22 (the total number of symptoms that could be endorsed); the PST was calculated by counting the total number of positively endorsed symptoms (the range of values for the PST variable was therefore 0-22); and the PSDI was calculated by dividing the PCSS total score by the PST value. In the case of a zero value for the PST scale score, the PSDI scale score was automatically assumed to be zero even though dividing by zero is “undefined,” mathematically speaking. After completing the transformations, descriptive statistics were conducted on the global indices of distress variables (e.g., PCSS-GSI, PCSS-PST, and PCSS-PSDI). Finally, independent samples t-tests were conducted in order to compare the symptom reports of males and females on the following baseline PCSS-related indices: the PCSS total score, the global indices of distress scales, and the factors that emerged from the factor analysis (Specific Aim 1).

Specific Aim 3: Identify pre-morbid/pre-injury characteristics that are predictive of post-concussion symptom reporting in the acute injury period.

Regression analyses were conducted to assess the extent to which the following a priori selected pre-morbid/pre-injury characteristics contribute to the post-concussion PCSS total score (PC-PCSS-TS), the main outcome variable:
• **Analysis 1: PCSS-Related Variables**
  
  o Analysis 1a: Predictor variables included the factors (e.g., symptom clusters) that emerged from the factor analysis of the PCSS at baseline (Specific Aim 1).
  
  o Analysis 1b: Predictor variables included the global indices of distress variables (PCSS-GSI, PCSS-PST, and PCSS-PSDI) at baseline (Specific Aim 2).

• **Analysis 2: Demographic/Social Variables**
  
  o Predictor variables included gender, concussion history, body mass index, and diagnosis of a developmental disorder (e.g., ADHD, learning disability).

• **Analysis 3: Affective Variables**
  
  o Predictor variables included the baseline BDI-FS total score and the neuroticism personality factor derived from the baseline NEO-FFI.

• **Analysis 4: Neurocognitive Variables**
  
  o Predictor variables included the baseline WTAR standard score and a baseline neurocognitive composite score (a description of how this variable was calculated is provided below).

Prior to performing the regression analyses, correlations were conducted using Pearson’s r to determine the relationship between the predictor variables and the outcome variable, as well as the intercorrelations between the predictor variables, for each analysis listed above. Binary logistic regression was then used to predict the PC-PCSS-TS as a categorical outcome variable. The PC-PCSS-TS was categorized into two groups—“low symptoms” and “high symptoms”—based on the median value of the baseline PCSS total score. Those having PCSS total scores falling at or below the median were included in the “low symptoms” group, and those with scores falling above the median were included in the “high symptoms” group.
In order to derive the baseline neurocognitive composite score (mentioned above in Analysis 4), the following baseline neurocognitive test indices were converted to standard scores so that all measures were on the same metric: BVMT-R Total Immediate Recall, BVMT-R Total Delayed Recall, HVLT-R Total Immediate Recall, HVLT-R Total Delayed Recall, Digit Span Forward, Digit Span Backward, SDMT-Total Correct, SDMT-Incidental Memory, CTMT-1 Time, and CTMT-2 Time, PSU Cancellation Task Total Correct, Vigil-Total Omissions, Vigil-Total Commissions, Vigil-Average Delay, SCWT-Word Task Time, SCWT-Color/Word Task Time, ImPACT Verbal Memory Composite, ImPACT Visual Memory Composite, ImPACT Visual Motor Speed Composite, ImPACT Reaction Time Composite, and ImPACT Impulse Control Composite. Standard scores have a mean of 100 and a standard deviation of 15. The sample mean and sample standard deviation for the athletes’ baseline scores were used to calculate the standard scores. However, because of the widely established gender differences within the neuropsychological assessment literature (Lezak, Howieson, & Loring, 2004), independent samples t-tests were first conducted to determine whether there were significant gender differences on any of the neurocognitive test indices in this sample. Furthermore, it is important to note that for many of the test indices, higher scores indicate better performance; in these cases, standard scores were calculated by subtracting the sample mean from the raw (observed) score of each individual. However, when higher scores indicate poorer performance (i.e., CTMT-1 & 2 Time, Vigil-Total Omissions, Vigil-Total Commissions, Vigil-Average Delay, SCWT-Word Task & Color/Word Task Time, ImPACT Reaction Time Composite, and ImPACT Impulse Control Composite), standard scores were calculated by subtracting the observed score from the sample mean. As a result, for all standard scores, higher scores indicate better performance.
After all of the test indices were converted to standard scores, an EFA was performed on the 21 test indices. Factors were extracted using Principal Components Analysis with Varimax rotation and Kaiser normalization. It was determined a priori that all test indices with component loadings greater than 0.4 on the first factor would be used to derive the final neurocognitive composite score. Finally, in order to verify the internal consistency of the neurocognitive composite score, Cronbach’s α was employed.

**Specific Aim 4: Identify injury-specific characteristics that are predictive of post-concussion symptom reporting in the acute injury period.**

Regression analyses were conducted to assess the extent to which injury-specific characteristics identified a priori contribute to the PC-PCSS-TS. The following injury-specific characteristics were used as predictor variables in the regression: presence of loss of consciousness, presence of retrograde amnesia, and presence of anterograde amnesia. As in Specific Aim 3, correlations were conducted using Pearson’s r to determine the relationship between the predictor variables and the outcome variable, as well as the intercorrelations between the predictor variables. Binary logistic regression was then used to predict the PC-PCSS-TS as a categorical outcome variable. Again, the PC-PCSS-TS was categorized into either the “low symptoms” or “high symptoms” group based on the median value of the baseline PCSS total score. Those having PCSS total scores falling at or below the median were included in the “low symptoms” group, and those with scores falling above the median were included in the “high symptoms” group.
Specific Aim 5: Use results from Specific Aim 3 and 4 to determine the best predictors of symptom reporting in the acute injury period.

Binary logistic regression analyses were conducted to assess the extent to which statistically significant predictors in Specific Aims 3 and 4 best contribute to the PC-PCSS-TS. The same statistical procedures outlined above in Aims 3 & 4 were utilized in Aim 5.
Chapter 3. Results

Preliminary Data Analysis

In addition to checking the PCSS for missing values, the scores on the baseline PCSS (the computerized version) were compared to a similar symptom inventory (a paper/pencil version of the PCSS) that was administered towards the beginning of the neuropsychological test battery. Three of the 702 athletes had discrepant symptom severity ratings on the computerized PCSS as compared to the paper/pencil PCSS. Specifically, three athletes recorded “1’s” for every symptom on the computerized PCSS measure (for a total score of 22), but recorded “0’s” for every symptom on the paper/pencil PCSS measure (for a total score of 0). Given that the total scores for these athletes appeared to differ as a function of administration format, it is noteworthy to mention the design of the computerized PCSS measure. The computerized PCSS lists one symptom per screen shot, with a scale ranging from 1-6 where the athletes are instructed to select the score that best represents how they are currently feeling. Additionally, there is a check box above the 1-6 scale where athletes can check “none,” indicating absence of that symptom. When taking this design into consideration, it seems likely that athletes may fail to recognize that they can check “none,” and as a result, end up checking “1” for all symptoms. For these reasons, the individual symptom scores for the three athletes were changed from “1’s” to “0’s” for every symptom, resulting in a total score of 0 for the computerized PCSS measure.

Primary Data Analysis

Specific Aim 1: Conduct a factor analysis to determine the factor structure of the PCSS.

Four distinct factors—or symptom clusters—emerged from the EFA, accounting for 48.21% of the variance with a Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy of
0.85. Three of the 22 PCSS items (headache, sleeping more than usual, and numbness/tingling) were not included in the final factor solution because the rotated component loadings were less than the a priori established cutoff of 0.4; however, the remaining 19 PCSS items had loadings of 0.4 or greater and were thus included in the solution. The four symptom clusters consisted of the following: (1) a cognitive factor comprised of 4 items, eigenvalue = 6.06, accounting for 27.53% of the variance; (2) a physical factor comprised of 7 items, eigenvalue = 1.76, accounting for 7.98% of the variance; (3) an affective factor comprised of 4 items, eigenvalue = 1.50, accounting for 6.80% of the variance; and (4) a sleep factor comprised of 4 items, eigenvalue = 1.30, accounting for 5.90% of the variance. Table 4 lists all 22 PCSS items and their associated factor loadings for each symptom cluster, Table 5 contains descriptive statistics and reliability estimates for the symptom clusters, and Figure 1 graphically illustrates the factor loadings for the retained symptoms. Importantly, four PCSS items (fatigue, drowsiness, irritability, and visual problems) cross-loaded on two factors and were subsequently assigned to the factor with the largest loading (see Table 4). The final factor solution is presented in Table 6.
### Table 4. Baseline PCSS Symptoms and Factor Loadings

<table>
<thead>
<tr>
<th>PCSS Symptoms</th>
<th>Factor 1: Cognitive</th>
<th>Factor 2: Physical</th>
<th>Factor 3: Affective</th>
<th>Factor 4: Sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache^b</td>
<td>.381</td>
<td>.302</td>
<td>.139</td>
<td>-.042</td>
</tr>
<tr>
<td>Nausea</td>
<td>.030</td>
<td>.674^a</td>
<td>.079</td>
<td>.191</td>
</tr>
<tr>
<td>Vomiting</td>
<td>-.041</td>
<td>.692^a</td>
<td>.116</td>
<td>.186</td>
</tr>
<tr>
<td>Balance Problems</td>
<td>.261</td>
<td>.586^a</td>
<td>.129</td>
<td>-.108</td>
</tr>
<tr>
<td>Dizziness</td>
<td>.363</td>
<td>.605^a</td>
<td>-.005</td>
<td>.140</td>
</tr>
<tr>
<td>Fatigue^c</td>
<td>.434</td>
<td>.164</td>
<td>.139</td>
<td>.517^a</td>
</tr>
<tr>
<td>Trouble Falling Asleep</td>
<td>.118</td>
<td>.105</td>
<td>.117</td>
<td>.706^a</td>
</tr>
<tr>
<td>Sleeping More than Usual^b</td>
<td>.376</td>
<td>.271</td>
<td>.168</td>
<td>-.143</td>
</tr>
<tr>
<td>Sleeping Less than Usual</td>
<td>.066</td>
<td>.163</td>
<td>.068</td>
<td>.823^a</td>
</tr>
<tr>
<td>Drowsiness^c</td>
<td>.415</td>
<td>.248</td>
<td>.021</td>
<td>.456^a</td>
</tr>
<tr>
<td>Sensitivity to Light</td>
<td>.219</td>
<td>.417^a</td>
<td>.031</td>
<td>.286</td>
</tr>
<tr>
<td>Sensitivity to Noise</td>
<td>-.075</td>
<td>.532^a</td>
<td>.173</td>
<td>.266</td>
</tr>
<tr>
<td>Irritability^c</td>
<td>.424</td>
<td>.142</td>
<td>.435^a</td>
<td>.048</td>
</tr>
<tr>
<td>Sadness</td>
<td>.139</td>
<td>.127</td>
<td>.847^a</td>
<td>.111</td>
</tr>
<tr>
<td>Nervousness</td>
<td>.166</td>
<td>.110</td>
<td>.728^a</td>
<td>.105</td>
</tr>
<tr>
<td>Feeling More Emotional</td>
<td>.185</td>
<td>.125</td>
<td>.832^a</td>
<td>.076</td>
</tr>
<tr>
<td>Numbness or Tingling^c</td>
<td>.242</td>
<td>.320</td>
<td>.056</td>
<td>.031</td>
</tr>
<tr>
<td>Feeling Slowed Down</td>
<td>.619^a</td>
<td>.193</td>
<td>.137</td>
<td>.225</td>
</tr>
<tr>
<td>Feeling Mentally “Foggy”^c</td>
<td>.567^a</td>
<td>.109</td>
<td>.150</td>
<td>.323</td>
</tr>
<tr>
<td>Difficulty Concentrating</td>
<td>.717^a</td>
<td>-.009</td>
<td>.251</td>
<td>.282</td>
</tr>
<tr>
<td>Difficulty Remembering</td>
<td>.744^a</td>
<td>.038</td>
<td>.113</td>
<td>.099</td>
</tr>
<tr>
<td>Visual Problems^c</td>
<td>.408</td>
<td>.457^a</td>
<td>.061</td>
<td>.028</td>
</tr>
</tbody>
</table>

**Note:** N = 702 (523 Males, 179 Females); ^a Item met factor loading criteria (>0.4); ^b Item eliminated from solution as it did not meet factor loading criteria; ^c Item cross-loaded on 2 factors.

### Table 5. Descriptive Statistics for the PCSS Symptom Clusters

<table>
<thead>
<tr>
<th>PCSS Symptom Clusters</th>
<th>Number of Items</th>
<th>Mean</th>
<th>SD</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Cronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive</td>
<td>4</td>
<td>1.03</td>
<td>2.34</td>
<td>3.33</td>
<td>13.48</td>
<td>0.76</td>
</tr>
<tr>
<td>Physical</td>
<td>7</td>
<td>0.58</td>
<td>1.77</td>
<td>3.89</td>
<td>16.63</td>
<td>0.74</td>
</tr>
<tr>
<td>Affective</td>
<td>4</td>
<td>1.26</td>
<td>2.72</td>
<td>3.20</td>
<td>12.65</td>
<td>0.77</td>
</tr>
<tr>
<td>Sleep</td>
<td>4</td>
<td>2.08</td>
<td>3.25</td>
<td>2.18</td>
<td>5.59</td>
<td>0.73</td>
</tr>
</tbody>
</table>

**Note:** N = 702 (523 Males, 179 Females).
Figure 1. Baseline PCSS Factor Analysis: Symptoms and Associated Factor Loadings

Table 6. Baseline PCSS Factor Analysis: Final Factors and their Associated Symptoms

<table>
<thead>
<tr>
<th>Factor 1: Cognitive</th>
<th>Factor 2: Physical</th>
<th>Factor 3: Affective</th>
<th>Factor 4: Sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeling Slowed Down</td>
<td>Nausea</td>
<td>Irritability</td>
<td>Fatigue</td>
</tr>
<tr>
<td>Feeling Mentally “Foggy”</td>
<td>Vomiting</td>
<td>Sadness</td>
<td>Trouble Falling Asleep</td>
</tr>
<tr>
<td>Difficulty Concentrating</td>
<td>Balance Problems</td>
<td>Nervousness</td>
<td>Sleeping Less Than Usual</td>
</tr>
<tr>
<td>Difficulty Remembering</td>
<td>Dizziness</td>
<td>Feeling More Emotional</td>
<td>Drowsiness</td>
</tr>
<tr>
<td></td>
<td>Sensitivity to Light</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sensitivity to Noise</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual Problems</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Specific Aim 2: Apply the SCL-90-R framework (the “global indices of distress”) to the PCSS in order to better characterize athletes’ symptom profiles.

Descriptive statistics for the SCL-90-R global indices of distress variables are presented in Table 7. When examining the sample altogether, the PCSS-GSI and PCSS-PST had positive skewness and kurtosis, and the PCSS-PSDI had positive skewness and negative kurtosis. When examining the sample by gender, the global indices of distress variables had similar skewness and kurtosis, though the variables were less skewed in the female sample (skewness: GSI = 2.01, PST = 5.83, and PSDI = -0.46) as compared to the male sample (skewness: GSI = 2.42, PST = 2.76, and PSDI = 0.73). Furthermore, t-tests revealed significantly higher scores for females compared with males on the following PCSS-related indices: the baseline PCSS total score, \( t(700) = -2.20, p < .05 \), the PCSS-GSI, \( t(700) = -2.20, p < .05 \), and the affective symptom cluster derived from Specific Aim 1, \( t(253) = -3.19, p < .05 \). Additionally, there was a trend towards significance on the PCSS-PST, \( t(700) = -1.88, p = .06 \), with higher scores for females compared with males. Results of the t-test comparisons are summarized in Table 8.
Table 7. Sample Descriptive Statistics for Baseline SCL-90-R Global Indices of Distress Variables

<table>
<thead>
<tr>
<th>SCL-90-R Global Indices of Distress Variables</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCSS Global Severity Index (GSI)</td>
<td>0.25</td>
<td>0.38</td>
<td>0.00</td>
<td>2.14</td>
<td>.09</td>
<td>2.29</td>
<td>5.75</td>
</tr>
<tr>
<td>PCSS Positive Symptom Total (PST)</td>
<td>2.86</td>
<td>4.20</td>
<td>0.00</td>
<td>22.00</td>
<td>1.00</td>
<td>2.58</td>
<td>7.84</td>
</tr>
<tr>
<td>PCSS Positive Symptom Distress Index (PSDI)</td>
<td>1.25</td>
<td>1.20</td>
<td>0.00</td>
<td>5.00</td>
<td>1.00</td>
<td>0.65</td>
<td>-0.41</td>
</tr>
</tbody>
</table>

*Note: N = 702 (523 Males, 179 Females).*

Table 8. *t*-test Results Comparing Males and Females on Baseline ImPACT PCSS Symptom Indices

<table>
<thead>
<tr>
<th>Baseline ImPACT PCSS Symptom Indices</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>p</th>
<th>Cohen’s Effect Sizes (d)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global Severity Index</td>
<td>0.24</td>
<td>0.31</td>
<td>-2.20</td>
<td>.028</td>
<td>0.18</td>
</tr>
<tr>
<td>Positive Symptom Total</td>
<td>2.69</td>
<td>3.37</td>
<td>-1.88</td>
<td>.061</td>
<td>0.16</td>
</tr>
<tr>
<td>Positive Symptom Distress Index</td>
<td>1.21</td>
<td>1.38</td>
<td>-1.68</td>
<td>.093</td>
<td>0.14</td>
</tr>
<tr>
<td>Cognitive Symptom Cluster</td>
<td>0.96</td>
<td>1.22</td>
<td>-1.27</td>
<td>.206</td>
<td>0.11</td>
</tr>
<tr>
<td>Physical Symptom Cluster</td>
<td>0.59</td>
<td>0.58</td>
<td>0.03</td>
<td>.979</td>
<td>0.01</td>
</tr>
<tr>
<td>Affective Symptom Cluster</td>
<td>1.05</td>
<td>1.89</td>
<td>-3.19</td>
<td>.002</td>
<td>0.29</td>
</tr>
<tr>
<td>Sleep Symptom Cluster</td>
<td>2.03</td>
<td>2.24</td>
<td>-0.75</td>
<td>.453</td>
<td>0.06</td>
</tr>
<tr>
<td>Total Symptom Score</td>
<td>5.19</td>
<td>6.77</td>
<td>-2.20</td>
<td>.028</td>
<td>0.19</td>
</tr>
</tbody>
</table>

*Note: N = 702 (523 Males, 179 Females); *Cohen’s effect sizes (d): small (0.2), medium (0.5), large (0.8).*
Specific Aim 3: Identify pre-morbid/pre-injury characteristics that are predictive of post-concussion symptom reporting in the acute injury period.

Analysis 1: PCSS-Related Variables

Preliminary corralational analyses revealed no significant relationships between any of the PCSS-related predictor variables (e.g., the cognitive, physical, affective, or sleep symptom clusters and the global indices of distress predictors) and the PC-PCSS-TS. However, not surprisingly, significant relationships were discovered between the following symptom clusters: physical with cognitive ($r = .45$, $p = .001$), physical with affective ($r = .68$, $p < .001$), physical with sleep ($r = .71$, $p < .001$), cognitive with affective ($r = .70$, $p < .001$), cognitive with sleep ($r = .38$, $p = .004$), and affective with sleep ($r = .60$, $p < .001$). Additionally, significant relationships were found between the following global indices of distress variables: PCSS-GSI with PCSS-PST ($r = .93$, $p < .001$), PCSS-GSI with PCSS-PSDI ($r = .46$, $p < .001$), and PCSS-PST with PCSS-PSDI ($r = .30$, $p = .025$).

Analysis 1a: PCSS Symptom Clusters Predicting PC-PCSS-TS. A test of the full model with the four predictor variables against a constant-only model was statistically significant, $\chi^2(4, N=55)=12.59$, $p < .05$, indicating that the baseline symptom clusters, as a set, reliably distinguished between athletes with low and high PC-PCSS-TS’s. However, a Nagelkerke’s $R^2$ of .29 suggested a moderately weak relationship between the predictors and the PC-PCSS-TS. Classification results indicated that 29.40% of the athletes with low PC-PCSS-TS’s were correctly classified, and 94.70% of the athletes with high PC-PCSS-TS’s were correctly classified, with the model correctly predicting 74.50% of the cases. Table 9 shows regression coefficients and standard errors, Wald statistics, and odds ratios for the four symptom clusters (as well as for the variables listed in the analyses below).
Table 9. Logistic Regression for Pre-Morbid/Pre-Injury Characteristics Predicting Dichotomized Post-Concussion PCSS Scores

<table>
<thead>
<tr>
<th>Predictor Variable</th>
<th>β</th>
<th>SE β</th>
<th>Wald’s $\chi^2$ (df = 1)</th>
<th>p</th>
<th>$e^\beta$ (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analysis 1a: PCSS Symptom Clusters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.03</td>
<td>0.43</td>
<td>5.65</td>
<td>.017</td>
<td>2.79</td>
</tr>
<tr>
<td>Cognitive Symptoms</td>
<td>-0.10</td>
<td>0.21</td>
<td>0.24</td>
<td>.623</td>
<td>0.90</td>
</tr>
<tr>
<td>Physical Symptoms</td>
<td>-0.91</td>
<td>0.43</td>
<td><strong>4.52</strong></td>
<td><strong>.033</strong></td>
<td>0.40</td>
</tr>
<tr>
<td>Affective Symptoms</td>
<td>1.16</td>
<td>0.53</td>
<td><strong>4.70</strong></td>
<td><strong>.030</strong></td>
<td>3.18</td>
</tr>
<tr>
<td>Sleep Symptoms</td>
<td>-0.06</td>
<td>0.16</td>
<td>0.13</td>
<td>.716</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>Analysis 1b: SCL-90-R Global Indices of Distress</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.18</td>
<td>0.50</td>
<td>5.63</td>
<td>.018</td>
<td>3.24</td>
</tr>
<tr>
<td>GSI</td>
<td>2.85</td>
<td>2.43</td>
<td>1.38</td>
<td>.240</td>
<td>17.27</td>
</tr>
<tr>
<td>PST</td>
<td>-0.25</td>
<td>0.19</td>
<td>1.79</td>
<td>.181</td>
<td>0.78</td>
</tr>
<tr>
<td>PSDI</td>
<td>-0.25</td>
<td>0.32</td>
<td>0.61</td>
<td>.435</td>
<td>0.78</td>
</tr>
<tr>
<td><strong>Analysis 2: Demographic/Social Variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-4.09</td>
<td>2.63</td>
<td>2.41</td>
<td>.121</td>
<td>0.02</td>
</tr>
<tr>
<td>Gender</td>
<td>2.12</td>
<td>1.25</td>
<td>2.89</td>
<td>.089</td>
<td>8.35</td>
</tr>
<tr>
<td>PHI (1 vs. 0)</td>
<td>1.75</td>
<td>0.88</td>
<td>3.93</td>
<td>.048</td>
<td>5.73</td>
</tr>
<tr>
<td>PHI (2 or more vs. 0)</td>
<td>1.95</td>
<td>0.95</td>
<td>4.19</td>
<td>.041</td>
<td>7.05</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>0.11</td>
<td>0.08</td>
<td>1.82</td>
<td>.177</td>
<td>1.12</td>
</tr>
<tr>
<td>Development Disorder</td>
<td>0.29</td>
<td>0.83</td>
<td>0.13</td>
<td>.723</td>
<td>1.34</td>
</tr>
<tr>
<td><strong>Analysis 3: Affective Variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.51</td>
<td>0.89</td>
<td>2.86</td>
<td>.091</td>
<td>4.51</td>
</tr>
<tr>
<td>BDI-FS Total Score</td>
<td>-0.67</td>
<td>0.63</td>
<td>1.12</td>
<td>.290</td>
<td>0.51</td>
</tr>
<tr>
<td>Neuroticism</td>
<td>-.02</td>
<td>0.05</td>
<td>0.16</td>
<td>.686</td>
<td>0.98</td>
</tr>
<tr>
<td><strong>Analysis 4: Neurocognitive Variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>10.73</td>
<td>5.25</td>
<td>4.18</td>
<td>.041</td>
<td>45851.97</td>
</tr>
<tr>
<td>NC Composite</td>
<td>-0.12</td>
<td>0.05</td>
<td><strong>5.10</strong></td>
<td><strong>.024</strong></td>
<td>0.89</td>
</tr>
<tr>
<td>WTAR</td>
<td>0.02</td>
<td>0.04</td>
<td>0.13</td>
<td>.717</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Note: N = 55. Abbreviations: GSI = Global Severity Index; PST = Positive Symptom Total; PSDI = Positive Symptom Distress Index; PHI = Previous Head Injuries; BDI-FS = Beck Depression Inventory – Fast Screen; NC = Neurocognitive; WTAR = Wechsler Test of Adult Reading.

According to the Wald criterion, both the physical and affective symptom clusters made a significant contribution to the prediction of the PC-PCSS-TS, $\chi^2(1, N=55)=4.52$, p<.05 and $\chi^2(1, N=55)=4.70$, p<.05, respectively. Interestingly, examination of the odds ratios suggest that an
athlete is 60% less likely to fall within the high PC-PCSS-TS group for each one unit increase in physical symptoms. However, when the affective symptom cluster is increased by one point, athletes are three times more likely to demonstrate a high PC-PCSS-TS. Thus, while both physical and affective symptoms at baseline appear to distinguish between athletes who demonstrate low and high symptoms following a concussion, baseline physical symptoms are negatively associated with a high PC-PCSS-TS whereas baseline affective symptoms are positively associated with a high PC-PCSS-TS.

**Analysis 1b: Global Indices of Distress Variables Predicting PC-PCSS-TS.** A test of the full model with the three predictor variables against a constant-only model was not statistically significant, $\chi^2(3, N=55)=2.50$, $p=.476$, indicating that the global indices of distress variables at baseline do not reliably distinguish between athletes with low and high PC-PCSS-TS’s.

**Analysis 2: Demographic/Social Variables**

Preliminary correlational analyses revealed no significant relationships between any of the demographic/social variables (e.g., gender, concussion history, body mass index, and diagnosis of a developmental disorder) and the PC-PCSS-TS. However, when evaluating the intercorrelations between the predictor variables, a significant relationship was found between gender and body mass index ($r=.31$, $p=.024$).

A test of the full model with the four demographic/social predictors against a constant-only model was not statistically significant, $\chi^2(4, N=54)=9.14$, $p=.104$, indicating that the predictors, as a set, do not reliably distinguish between athletes with low and high PC-PCSS-TS’s.
Analysis 3: Affective Variables

Preliminary correlational analyses revealed no significant relationships between either of the affective variables (e.g., BDI-FS total score and the neuroticism personality factor) and the PC-PCSS-TS. Similarly, no intercorrelations were found between the predictor variables.

A test of the full model with both baseline affective predictor variables against a constant-only model was not statistically significant, χ²(2, N=50)=0.68, p=.713, indicating that the affective predictor variables do not reliably distinguish between athletes with low and high PC-PCSS-TS’s.

Analysis 4: Neurocognitive Variables

Prior to running the regression for Analysis 4, the neurocognitive composite score was computed. Table 10 lists the t-test results comparing males and females on the baseline neurocognitive test indices. Twelve of the 21 neurocognitive indices were significantly different for males and females. Given that more than half of the indices significantly differed based on gender, independent means and standard deviations were used to calculate the standard scores. The EFA of the neurocognitive variables revealed that 14 of the 21 indices had component loadings of 0.4 or greater on factor one. Table 11 lists the retained neurocognitive test indices and their associated component loadings. The final neurocognitive composite variable was found to be highly reliable (14 items; α = .82).
## Table 10. t-test Results Comparing Males and Females on Baseline Neurocognitive Test Indices

<table>
<thead>
<tr>
<th>Baseline Neurocognitive Test Indices</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>p</th>
<th>Cohen’s Effect Sizes (d)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td></td>
</tr>
<tr>
<td>Vigil Total Omissions^</td>
<td>1.62</td>
<td>1.74</td>
<td>2.97</td>
<td>3.84</td>
<td>-0.43</td>
</tr>
<tr>
<td>Vigil Total Commissions^</td>
<td>2.58</td>
<td>2.03</td>
<td>2.73</td>
<td>2.28</td>
<td>2.59</td>
</tr>
<tr>
<td>Vigil Average Delay^</td>
<td>413.17</td>
<td>410.79</td>
<td>40.48</td>
<td>38.17</td>
<td>0.68</td>
</tr>
<tr>
<td>ImPACT Verbal Memory Composite</td>
<td>84.05</td>
<td>86.45</td>
<td>11.23</td>
<td>10.26</td>
<td>-2.50</td>
</tr>
<tr>
<td>ImPACT Visual Memory Composite</td>
<td>76.17</td>
<td>75.45</td>
<td>12.84</td>
<td>13.32</td>
<td>0.63</td>
</tr>
<tr>
<td>ImPACT Visual Motor Speed Composite</td>
<td>36.14</td>
<td>38.00</td>
<td>7.27</td>
<td>7.23</td>
<td>-2.95</td>
</tr>
<tr>
<td>ImPACT Reaction Time Composite^</td>
<td>0.60</td>
<td>0.59</td>
<td>0.09</td>
<td>0.07</td>
<td>1.52</td>
</tr>
<tr>
<td>ImPACT Impulse Control Composite^</td>
<td>10.99</td>
<td>9.35</td>
<td>17.20</td>
<td>14.98</td>
<td>1.13</td>
</tr>
<tr>
<td>BVMT-R Total Immediate Recall</td>
<td>27.24</td>
<td>28.97</td>
<td>5.37</td>
<td>4.71</td>
<td>-4.06</td>
</tr>
<tr>
<td>BVMT-R Total Delayed Recall</td>
<td>10.38</td>
<td>10.85</td>
<td>1.75</td>
<td>1.47</td>
<td>-3.48</td>
</tr>
<tr>
<td>HVLT-R Total Immediate Recall</td>
<td>26.47</td>
<td>27.47</td>
<td>3.85</td>
<td>3.46</td>
<td>-3.06</td>
</tr>
<tr>
<td>HVLT-R Total Delayed Recall</td>
<td>9.37</td>
<td>9.81</td>
<td>1.95</td>
<td>1.56</td>
<td>-3.04</td>
</tr>
<tr>
<td>SDMT Total Correct</td>
<td>59.73</td>
<td>63.52</td>
<td>11.87</td>
<td>9.75</td>
<td>-4.20</td>
</tr>
<tr>
<td>SDMT Incidental Memory</td>
<td>13.21</td>
<td>13.38</td>
<td>2.82</td>
<td>2.55</td>
<td>-0.73</td>
</tr>
<tr>
<td>Digit Span Forward</td>
<td>11.47</td>
<td>11.16</td>
<td>2.17</td>
<td>1.94</td>
<td>1.77</td>
</tr>
<tr>
<td>Digit Span Backward</td>
<td>7.76</td>
<td>7.84</td>
<td>2.47</td>
<td>2.33</td>
<td>-0.38</td>
</tr>
<tr>
<td>SCWT-Word Task Time^</td>
<td>54.56</td>
<td>52.16</td>
<td>10.52</td>
<td>7.89</td>
<td>2.76</td>
</tr>
<tr>
<td>SCWT-Color/Word Task Time^</td>
<td>115.01</td>
<td>104.91</td>
<td>20.61</td>
<td>19.73</td>
<td>5.64</td>
</tr>
<tr>
<td>PSU Cancellation Test Total Correct</td>
<td>46.61</td>
<td>47.67</td>
<td>10.87</td>
<td>10.51</td>
<td>-1.13</td>
</tr>
<tr>
<td>Trail Making Test Trial 1 Time^</td>
<td>39.00</td>
<td>36.53</td>
<td>13.30</td>
<td>10.97</td>
<td>2.44</td>
</tr>
<tr>
<td>Trail Making Test Trial 2 Time^</td>
<td>41.14</td>
<td>36.21</td>
<td>20.17</td>
<td>15.78</td>
<td>3.31</td>
</tr>
</tbody>
</table>

*p* Note: N=702. Abbreviations: BVMT-R = Brief Visuospatial Memory Test-Revised; HVLT-R = Hopkins Verbal Memory Test-Revised; SDMT = Symbol Digit Modalities Test; SCWT = Stroop Color-Word Test. Footnotes: *Cohen’s effect sizes: small (0.2), medium (0.5), large (0.8); ^High t-scores indicate worse performance on this test.
Table 11. Retained Neurocognitive Test Indices and their Associated Component Loadings

<table>
<thead>
<tr>
<th>Test Index</th>
<th>Component 1 Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td>ImPACT Verbal Memory Composite</td>
<td>0.63</td>
</tr>
<tr>
<td>ImPACT Visual Memory Composite</td>
<td>0.57</td>
</tr>
<tr>
<td>ImPACT Visual Motor Speed Composite</td>
<td>0.66</td>
</tr>
<tr>
<td>ImPACT Reaction Time Composite</td>
<td>-0.52</td>
</tr>
<tr>
<td>BVMT-R Total Immediate Recall</td>
<td>0.54</td>
</tr>
<tr>
<td>BVMT-R Total Delayed Recall</td>
<td>0.51</td>
</tr>
<tr>
<td>HVLT-R Total Immediate Recall</td>
<td>0.55</td>
</tr>
<tr>
<td>HVLT-R Total Delayed Recall</td>
<td>0.56</td>
</tr>
<tr>
<td>Symbol Digit Modalities Test – Total Correct</td>
<td>0.67</td>
</tr>
<tr>
<td>Symbol Digit Modalities Test – Incidental Memory</td>
<td>0.46</td>
</tr>
<tr>
<td>Stroop Word Time</td>
<td>-0.41</td>
</tr>
<tr>
<td>Stroop Color-Word Time</td>
<td>-0.57</td>
</tr>
<tr>
<td>Comprehensive Trail Making Trial 1 (Trail 2 or 3)</td>
<td>-0.48</td>
</tr>
<tr>
<td>Comprehensive Trail Making Test Trial 2 (Trail 4 or 5)</td>
<td>-0.49</td>
</tr>
</tbody>
</table>

Preliminary correlational analyses revealed no significant relationships between either of the neurocognitive variables (e.g., WTAR standard score and the neurocognitive composite score) and the PC-PCSS-TS. However, when evaluating the intercorrelations between the predictor variables, a significant relationship was found between the WTAR standard score and the neurocognitive composite score ($r=.45$, $p=.001$).

A test of the full model with both predictors against a constant-only model was statistically significant, $\chi^2(2, N=50)=6.80$, $p<.05$, indicating that the neurocognitive variables, as a set, reliably distinguished between athletes with low and high PC-PCSS-TS’s. However, a Nagelkerke’s $R^2$ of .18 suggested a relatively weak relationship between the set of predictors and the PC-PCSS-TS. Classification results indicated that 26.70% of the athletes with low PC-PCSS-TS’s were correctly classified, and 88.60% of the athletes with high PC-PCSS-TS’s were correctly classified, with the model correctly predicting 70.00% of the cases. According to the Wald criterion, only the neurocognitive composite score reliably predicted the PC-PCSS-TS,
χ²(1, N=50)=5.10, p<.05. The data show that an athlete is 11% less likely to fall within the high PC-PCSS-TS group for each one unit increase in the neurocognitive composite score.

Specific Aim 4: Identify injury-specific characteristics that are predictive of post-concussion symptom reporting in the acute injury period.

Preliminary correlational analyses revealed no significant relationships between any of the injury-specific characteristics (e.g., loss of consciousness, retrograde amnesia, and anterograde amnesia) and the PC-PCSS-TS. However, significant relationships were discovered between the following injury-specific variables: loss of consciousness with anterograde amnesia (r=.37, p=.006) and retrograde amnesia with anterograde amnesia (r=.39, p<.004).

A test of the full model with the three injury-specific variables against a constant-only model was not statistically significant, χ²(3, N =53)=3.55, p=.315, indicating that the predictors, as a set, do not reliably distinguish between athletes with low and high PC-PCSS-TS’s. The regression coefficients and standard errors, Wald statistics, and odds ratios for the injury-specific variables are listed in Table 12.

Table 12. Logistic Regression for Injury-Specific Characteristics Predicting Dichotomized Post-Concussion PCSS Scores

<table>
<thead>
<tr>
<th>Predictor Variable</th>
<th>β</th>
<th>SE β</th>
<th>Wald’s χ²</th>
<th>P</th>
<th>e^β (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.77</td>
<td>1.22</td>
<td>2.11</td>
<td>.146</td>
<td>5.85</td>
</tr>
<tr>
<td>Loss of Consciousness</td>
<td>-0.11</td>
<td>0.80</td>
<td>0.02</td>
<td>.888</td>
<td>0.89</td>
</tr>
<tr>
<td>Retrograde Amnesia</td>
<td>-1.72</td>
<td>1.20</td>
<td>2.07</td>
<td>.150</td>
<td>0.18</td>
</tr>
<tr>
<td>Anterograde Amnesia</td>
<td>1.01</td>
<td>0.71</td>
<td>2.00</td>
<td>.157</td>
<td>2.73</td>
</tr>
</tbody>
</table>

Note: N = 53.
Specific Aim 5: Use results from Specific Aim 3 and 4 to determine the best predictors of symptom reporting in the acute injury period.

Based on the results from Aims 3 and 4, the following predictor variables were utilized in the final regression analysis: physical symptom cluster, affective symptom cluster, and the neurocognitive composite score. Preliminary correlational analyses revealed no significant relationships between the neurocognitive composite score and the physical or affective symptom clusters.

A test of the full model with the three predictors against a constant-only model was statistically significant, $\chi^2(3, N=54)=17.05, p=.001$, indicating that the predictors, as a set, reliably distinguished between athletes with low and high PC-PCSS-TS’s. The Nagelkerke’s $R^2$ of .39 suggested a moderate relationship between the predictors and the PC-PCSS-TS.

Classification results indicated that 37.50% of the athletes with low PC-PCSS-TS’s were correctly classified, and 89.50% of the athletes with high PC-PCSS-TS’s were correctly classified, with the model correctly predicting 74.10% of the cases. Table 13 shows the regression coefficients and standard errors, Wald statistics, and odds ratios for the three predictors.

<table>
<thead>
<tr>
<th>Predictor Variable</th>
<th>$\beta$</th>
<th>$SE\beta$</th>
<th>Wald’s $\chi^2$ (df = 1)</th>
<th>$p$</th>
<th>$e^\beta$ (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>12.42</td>
<td>5.37</td>
<td>5.36</td>
<td>.021</td>
<td>247567.27</td>
</tr>
<tr>
<td>Physical Symptoms</td>
<td>-0.94</td>
<td>0.44</td>
<td>4.55</td>
<td>.033</td>
<td>0.39</td>
</tr>
<tr>
<td>Affective Symptoms</td>
<td>0.93</td>
<td>0.53</td>
<td>3.05</td>
<td>.081</td>
<td>2.52</td>
</tr>
<tr>
<td>NC Composite</td>
<td>-0.12</td>
<td>0.05</td>
<td>4.73</td>
<td>.030</td>
<td>0.89</td>
</tr>
</tbody>
</table>

*Note: N = 54.*
According to the Wald criterion, the physical symptom cluster and the neurocognitive composite made a significant contribution to the prediction of the PC-PCSS-TS, $\chi^2(1, N=54)=4.55$, $p<.05$ and $\chi^2(1, N=54)=4.73$, $p<.05$, respectively. Examination of the odds ratios suggest that an athlete is 61% less likely to fall within the high PC-PCSS-TS group for each one unit increase in physical symptoms and 11% less likely to fall within the high PC-PCSS-TS group for each one point increase in the neurocognitive composite score. Thus, both physical symptoms and the neurocognitive index are negatively associated with a high PC-PCSS-TS. The final regression model is presented in Figure 2.

**Figure 2. Final Regression Model Predicting Dichotomized Post-Concussion PCSS Scores**
Chapter 4. Discussion

The purpose of the present study was to better characterize athlete symptom reports, as well as to determine what impact pre-morbid and injury-specific characteristics have on the development and severity of post-concussion symptoms in the acute injury period following concussion. Several aims and hypotheses were put forward to address these objectives.

Specific Aim 1

To begin with, Specific Aim 1 sought to determine the factor structure of the PCSS at baseline. It was hypothesized that a factor analysis of the baseline PCSS would reveal four distinct symptom clusters, and the results supported this hypothesis. The baseline symptom clusters included: (1) a cognitive symptom cluster made up of 4 items, (2) a physical symptom cluster made up of 7 items; (3) an affective symptom cluster made up of 4 items; and (4) a sleep symptom cluster made up of 4 items. While a number of studies have conducted factor analyses on various symptom inventories including the PCSS, most have focused exclusively on post-concussion symptom reports. A recent study by Kontos et al. (2012), however, examined the factor structure of the PCSS at baseline and post-concussion. According to their study, the factor analysis of the baseline PCSS resulted in a four-factor solution consisting of (1) a cognitive-sensory symptom cluster, (2) a sleep-arousal symptom cluster, (3) a vestibular-somatic symptom cluster, and (4) an affective symptom cluster. The present results are remarkably consistent with Kontos et al. (2012) with respect to the structure of the affective and sleep symptom clusters, but the symptoms associated with the cognitive and physical symptom clusters in the present study differed from Kontos and colleagues’ findings. Specifically, the present results suggest a more homogeneous “cognitive” symptom cluster (i.e., symptoms include feeling slowed down, feeling
mentally foggy, difficulty concentrating, and difficulty remembering) and “physical” symptom cluster (i.e., symptoms include nausea, vomiting, balance problems, dizziness, sensitivity to light and noise, and visual problems) at baseline as compared to Kontos et al.’s “cognitive-sensory” and “vestibular-somatic” symptom clusters, which seemingly are comprised of more heterogeneous symptoms.

It is also important to note that in the present study, three symptoms (headache, sleeping more than usual, and numbness or tingling) from the PCSS did not meet factor loading criteria. In all three cases, the symptoms loaded across multiple factors at baseline but no one factor was above the 0.4 threshold, suggesting that even though these symptoms are endorsed by athletes at baseline, they do not clearly fall into one distinct symptom cluster. Consequently, these symptoms were eliminated from the final factor solution. Finally, four symptoms (fatigue, drowsiness, irritability, and visual problems) cross-loaded on at least two factors at the 0.4 level, and were ultimately assigned to the factor with the largest loading. Fatigue and drowsiness cross-loaded on the sleep and cognitive symptom clusters; irritability cross-loaded on the affective and cognitive symptom clusters; and visual problems cross-loaded on the physical and cognitive symptom clusters. Remarkably, in all four cases, the expected symptom cluster had the higher factor loading.

**Specific Aim 2**

Next, Specific Aim 2 sought to improve symptom characterization by applying the symptom framework of the SCL-90-R to the PCSS. As described above, the PCSS is often used to assess symptom severity in the sports community, but the PCSS total score is typically the only dependent variable that is evaluated in outcome studies (Covassin et al., 2012; Lovell et al.,
The problem with this approach is that it does not allow for an understanding of the total number of symptoms endorsed, nor does it allow for an understanding of the severity and specificity of the symptoms. Though no specific a priori hypotheses were generated for Specific Aim 2, it was thought that applying the SCL-90-R symptom characterization framework (e.g., the global indices of distress) to the PCSS would allow for a better understanding of athletes’ symptoms, as well as the ability to make more fine-grained predictions regarding symptom reporting.

With respect to the descriptive statistics for the baseline global indices of distress variables, the results were similar when examining the sample altogether and by gender in that most of the variables had positive skewness and kurtosis. This finding was not surprising given that more than one-third of the sample was asymptomatic (i.e., had a total score of 0, and therefore GSI, PST, and PSDI values of 0) at baseline. The more important finding, however, was that when the global indices of distress were examined by gender, the variables were less skewed in the female sample as compared to the male sample, suggesting that females endorsed more symptoms than males, overall. This supposition was confirmed when males and females were compared across the global indices of distress, the PCSS symptom clusters, and the PCSS total score at baseline. Although the only significant differences that were found between gender were the PCSS total score, the PCSS-GSI, and the affective symptom cluster, females endorsed more symptoms than males in all of the PCSS-related indices except for the physical symptom cluster (refer to Table 8). Although only a preliminary step in the direction of improving symptom characterization, the results suggest that further investigation of the application of the SCL-90-R global indices of distress to the PCSS is warranted.
Specific Aim 3

The purpose of Specific Aim 3 was to identify pre-morbid/pre-injury characteristics that are predictive of post-concussion symptom reporting in the acute injury period. Logistic regression analyses were conducted, examining PCSS-related variables, demographic/social variables, affective variables, and neurocognitive variables as predictors in separate regressions and predicting dichotomized (low vs. high) post-concussion PCSS total scores (PC-PCSS-TS). Although the hypotheses for Specific Aim 3 were not supported (e.g., gender, previous concussions, and the neuroticism personality factor were not predictive of post-concussion symptom reporting), both the physical and affective symptom clusters, as well as the neurocognitive composite score, reliably predicted athletes’ post-concussion symptom group (low vs. high PC-PCSS-TS).

With regard to the physical symptom cluster, the regression results suggested that athletes are 60% less likely to fall within the high symptoms group following a concussion for every one point increase in physical symptoms at baseline. While seeming somewhat paradoxical, there are several possible explanations for this finding. First, it is possible that the reason for endorsing the physical symptoms at baseline is simply no longer present post-concussion. Examples might include having a sickness or some sort of ailment at baseline that causes the athlete to feel nauseous or dizzy, for example. Another explanation for this paradoxical finding could be that athletes are over-endorsing physical symptoms at baseline. The athletes are told at the beginning of testing that the purpose of the baseline assessment is to “get a baseline for how you’re doing now, and that way, if you experience a concussion at any point as a result of your participation in athletics, we’ll have a way of comparing how you do then with how you do now.” In other words, the athletes are aware that their baseline test is going to be compared to
their post-concussion results (if they do sustain a concussion); therefore, it’s conceivable that some athletes may be tempted to over-report symptoms at baseline so that there is not such a discrepancy between their baseline symptom report and their post-concussion symptom report. Likewise, it is possible that athletes are under-endorsing symptoms at the post-concussion evaluation so that they are not withheld from play. A related matter is that physical symptoms (e.g., nausea, vomiting, balance problems, dizziness, sensitivity to light/noise, and visual problems) may be perceived by the athlete as being more severe than affective or sleep-related symptoms, for example, and therefore athletes may be concerned that they would be more likely to be excluded from sports participation if they endorsed any physical symptoms after sustaining a concussion. Regardless of the reasoning, the finding that baseline physical symptoms are negatively associated with a high PC-PCSS-TS is compelling, and warrants further investigation.

Next, the regression results also showed that affective symptoms at baseline distinguished between athletes who demonstrated low and high symptoms following a concussion. Specifically, for every one point increase in affective symptoms at baseline, athletes were three times more likely to demonstrate a high PC-PCSS-TS. This finding appears to be relatively straightforward, as it seems logical that those who endorse affective symptoms at baseline would show an increase in symptoms post-concussion. Finally, with respect to the neurocognitive composite score, the results illustrated that athletes are 11% less likely to fall within the high symptoms group following a concussion for every one point increase in the baseline neurocognitive composite score. In other words, athletes with a lower baseline neurocognitive composite score are more likely to endorse greater post-concussion symptoms, whereas athletes with a higher baseline neurocognitive composite score are more likely to endorse fewer post-concussion symptoms.
Very few studies have examined pre-morbid predictors of post-concussion symptoms in the acute injury period following sports-related concussion. While it appears as though research examining baseline PCSS-related variables (e.g., symptom clusters) as predictors for post-concussion symptom reporting is nonexistent, one study recently examined cognitive ability as a predictor of post-concussion symptoms (Fay et al., 2010). Specifically, the investigators sought to establish whether “cognitive reserve” moderated the relationship between mild TBI and post-concussion symptoms in a pediatric population. A neurocognitive composite score, similar to the one derived in this study, served as a proxy of cognitive reserve. The authors concluded that mild TBI participants with lower cognitive ability at 3-weeks post-injury reported greater post-concussion symptoms than mild TBI participants with higher cognitive ability at 3-weeks post-injury. Although there are notable differences between that study and the present one with respect to the study sample (i.e., children vs. collegiate athletes) and time course of variables (i.e., using post-injury cognitive ability to predict symptom reports one month after the injury vs. using baseline cognitive ability to predict symptom reporting within one week after the injury), the results are very consistent with one another, providing additional evidence in support of the notion that participants who demonstrate higher neurocognitive composite scores might be “protected” from the effects of concussion more so than those with lower neurocognitive composite scores.

Finally, it is worthwhile to note that Specific Aim 3 also demonstrated that a number of variables were not predictive of post-concussion symptom reporting. As mentioned above, gender and concussion history were not significant predictors, nor was the neuroticism personality factor. With respect to gender, the present results are inconsistent with the majority of past research that has documented clear gender differences in symptom reporting following a
One possibility that may explain this unexpected finding is that it is likely that the sample size had an influence on the predictability of the gender variable. Specifically, in our sample of 55 athletes, only eight were female. Thus, it is possible that had there been a more even distribution of males and females, gender may have emerged as a meaningful predictor of post-concussion symptoms. Finally, with respect to concussion history and the neuroticism personality factor, past research regarding their influence on symptom reporting has been mixed (Covassin et al., 2008; Garden et al., 2010; Moser et al., 2005; Ruff et al., 1996), and the present findings only further contribute to the disparate nature of this literature.

Specific Aim 4

Specific Aim 4 focused on injury-specific predictors, examining loss of consciousness, retrograde amnesia, and anterograde amnesia as predictors in the logistic regression, and predicting the dichotomized (low vs. high) PC-PCSS-TS. It was hypothesized that the presence of retrograde and anterograde amnesia would be predictive of an increased total symptom score post-concussion, but the results did not support this hypothesis. In fact, none of the three injury-specific predictors were found to significant predictors of post-concussion symptom reporting. However, it is important to note that all three variables (loss of consciousness, retrograde amnesia, and anterograde amnesia) were set up as dichotomized variables (yes or no), and as a result, the duration of impairment was not considered in the analysis. It is possible that had the duration of loss of consciousness or amnesia been taken into account, the findings would have been different. Nevertheless, the present results are consistent with some recent studies that have shown that these injury-specific variables are not predictive of post-concussion symptom
reporting (Lau, Collins, et al., 2011; Meehan III, Mannix, Stracciolini, Elbin, & Collins, in press; Ponsford et al., 2012). However, former work has shown that retrograde and/or anterograde amnesia are predictive of post-concussion symptom reporting (Collins et al., 2003; Lovell et al., 2003), indicating that further examination of these variables is necessary.

Specific Aim 5

Finally, the goal of Specific Aim 5 was to use the results from Specific Aims 3 and 4 to determine the best predictors of symptom reporting in the acute injury period. This aim was exploratory, and therefore specific hypotheses were not generated. Three variables were entered into the regression—the baseline physical symptom cluster, the affective symptom cluster, and the neurocognitive composite score—and the final analysis revealed that baseline physical symptoms and the neurocognitive composite were the best predictors of athletes’ post-concussion symptom group (low vs. high PC-PCSS-TS).

Clinical Implications

The factor analysis of the PCSS at baseline, as well as the application of the SCL-90-R global indices of distress to the PCSS, revealed that post-concussion-like symptoms are present in a seemingly healthy group of college-aged athletes, suggesting that these symptoms are not concussion-specific. These results are consistent with previous studies that have shown that traditional “post-concussion symptoms” are commonly reported in non-concussed groups (Garden & Sullivan, 2010; Wang, Chan, & Deng, 2006). Clinically, this is meaningful because it underscores the utility of making comparisons between pre and post-injury symptom profiles, and not to simply assume that post-concussion symptoms are the direct result of the concussion.
Moreover, the application of the global indices of distress to the PCSS is important because it may offer a promising new way of assessing symptoms. However, before this can be determined, it will be important to apply the global indices of distress to post-concussion PCSS data to see how the indices change from baseline to post-concussion. Additionally, it will be interesting to verify the factor structure of the post-concussion PCSS data, as well as determine whether gender differences exist among the post-concussion symptom clusters and global indices of distress variables.

The other major study objective was to establish whether there are pre-morbid/pre-injury and/or injury-specific predictors of post-concussion symptoms in the acute injury period following concussion. Identifying potential “risk factors” for post-concussion symptom reporting could be important for not only the athlete, but also for the coaching and training staff. First, with respect to athletes, the finding that certain personal characteristics are predictive of symptom reporting following concussion is relevant because this knowledge could impact decisions regarding return to play. Additionally, depending on the nature or severity of the injury, this information may have implications for whether or not the athletes choose to continue pursuing the sport, either at the collegiate level or making the transition to become professional athletes. As for the coaching and training staff, having an understanding of who is susceptible to developing greater post-concussion symptoms would likely influence return to play decisions from a coaching/management perspective, but could also potentially impact recruitment and scholarship decisions. Although these efforts are still in the beginning stages, the results of the present study suggest that continuing to explore predictors of post-concussion symptom reporting is a worthwhile endeavor.
Limitations

There are some notable limitations to this study that are worth highlighting. First, as indicated above, post-concussion symptoms are not specific to concussion or brain injury, and in fact, have been documented in other populations who have not sustained such injuries. For example, symptoms traditionally considered to be “post-concussion symptoms” have been reported in healthy adults (Chan, 2001; Lange, Iverson, & Rose, 2010; Wang et al., 2006), in trauma patients (Meares et al., 2006), in patients with orthopedic injuries and chronic pain (Gasquoine, 2000; Mickevičiene et al., 2004), and in depressed patients (Garden & Sullivan, 2010). It will be important to keep this in mind when interpreting the results, as it is possible that athletes may endorse symptoms that are not due to the concussion per se, but instead, are a result of social or environmental factors, for example, or secondary factors (e.g., depression, anxiety, pain, fatigue, etc.). Second, it has been established in the concussion literature that athletes have a tendency to minimize their symptoms because of the concern over return to play decisions (Bailey et al., 2006; Echemendia & Julian, 2001). As a result, the number or severity of symptoms athletes experience may not be accurately reflected in their PCSS report. However, because symptom reporting is vital to concussion management and return to play decisions, exploring the nature of athletes’ symptom reporting is meaningful. Third, although an a priori power analysis was calculated, and the number of post-concussion participants needed to obtain medium to large effects was obtained, it is certainly possible that had more subjects been included in the regression analyses that additional predictor variables would have been significant. Relatedly, the number of females included in the post-concussion sample is a shortcoming. Finally, the predictor variables that were utilized in the study were not exhaustive, and it is likely that a multitude of factors contribute to athletes’ development of post-concussion
symptoms in the acute injury period following concussion. Nevertheless, despite these limitations, the added value of the present study is thought to be significant.

Conclusions and Future Directions

The results of the current study lend support to the notion that pre-morbid characteristics have an influence on athletes’ symptom reporting post-concussion. Specifically, athletes who may be at risk for falling within the high post-concussion symptoms group can be identified based on their endorsement of baseline physical symptoms and their cognitive ability. While these are likely not the only variables that influence post-concussion symptom reporting, the findings suggest that there may be additional benefits to having athletes undergo routine baseline evaluations prior to engaging in athletics. Furthermore, although it remains unclear as to why endorsing more baseline physical symptoms makes an athlete less likely to fall within the high symptoms group post-concussion, it seems probable that motivation issues may be at play. In order to further address this puzzling finding, future studies should examine the relationship between motivation and symptom reporting, both at baseline and post-concussion. Additionally, it may be important to consider the method by which symptom inventories are administered. There is some evidence showing that the administration format influences participants’ responses (Krol, Mrazik, Naidu, Brooks, & Iverson, 2011; Villemure, Nolin, & Le Sage, 2011); therefore, future studies may want to further examine this possibility. Finally, the results suggest that athletes who exhibit higher neurocognitive scores at baseline may be less susceptible, or less vulnerable, to the effects of concussion. As indicated above, previous work has utilized neurocognitive composite scores as a proxy for cognitive reserve; thus, the results also imply that the concept of cognitive reserve may be applicable to this population. This finding is consistent
with Rabinowitz and Arnett’s (in press) recent study finding that athletes with higher and less variable cognitive functioning at baseline are less likely to show declines post-concussion.

Given the present findings, it follows that (1) post-concussion interventions should be developed that target athletes who are most susceptible to falling within the high post-concussion symptoms group and (2) that future studies should continue to examine potential predictors of post-concussion symptom reporting. Although this research is still in the early stages, it seems likely that as predictors of post-concussion symptoms are elucidated, that concussion management and return to play decisions will greatly improve.
References


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