OUTCOMES FOLLOWING SPORTS-RELATED CONCUSSION IN SCHOOL-AGED CHILDREN AND ADOLESCENTS: THE INFLUENCE OF PSYCHOLOGICAL FACTORS

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OUTCOMES FOLLOWING SPORTS-RELATED CONCUSSION IN SCHOOL-AGED CHILDREN AND ADOLESCENTS: THE INFLUENCE OF PSYCHOLOGICAL FACTORS

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Although neurocognitive performance has been a popular topic of investigation in sports-related concussion, biopsychosocial sequelae have received considerably less attention. We reviewed the literature on emotional and psychosocial functioning in school-aged children and adolescents following concussion. MEDLINE and PsycINFO database queries identified 604 studies examining psychological and/or social outcomes of mild traumatic brain injury in children, 11 of those specific to athletes. This small body of literature and extrapolation from the general pediatric concussion literature indicated behavioral disturbances present at least temporarily following injury. Postconcussive anxiety and depressive symptoms are common, though levels may be subclinical. Social and academic disruption was less clearly documented. To aid clinicians in anticipating the psychosocial needs of concussed student athletes, well-controlled and adequately powered research on emotional and psychosocial outcomes are needed. The impact of post-injury psychological functioning on concussion recovery is poorly understood, particularly in youth. To this end, we explored initial mood and sleep symptoms as predictors of prolonged symptom clearance in a sample of adolescents, controlling for previously established injury-related and demographic risk factors. Student athletes (aged 12-18, N=393, 55% male) evaluated in outpatient concussion clinics completed brief self-report anxiety, depression, sleep, and postconcussive symptom scales 0-2 weeks post-injury. Medical record review at three-month follow-up provided date of symptom clearance. Survival analysis for time to recovery was conducted based on 1) self-reported injury/medical factors: sex, psychiatric history, prior concussion history, loss of consciousness, amnesia, initial symptom severity, and 2) psychological factors: anxiety, depression, and sleep screeners. Having amnesia, greater postconcussive symptoms, and worse sleep quality decreased the odds of recovery across time points (HRs = 0.64-0.99, ps < .05) in the total sample. When separated by sex, only postconcussive symptoms were associated with recovery in females, while amnesia and depressive symptoms were the only significant predictors of recovery for males (HRs = 0.54–0.98, ps < .05). Our findings linked brief psychological screeners to prolonged recovery, even considering injury and medical factors. Assessment of mood and sleep may aid in identification of individuals at risk for worse outcomes, though further exploration of postconcussive psychological issues is warranted before drawing firm conclusions.

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CHAPTER ONE

General Dissertation Overview

EVIDENCE AND RATIONALE

A traumatic brain injury is a physiological injury induced by biomechanical forces dealt to the head. Concussion or mild traumatic brain injury (mTBI) is common, resulting in more than 1.2 million visits to emergency rooms in the U.S. every year (Faul & Coronado, 2015). Even with brief or no loss of consciousness, a concussion can result in transient changes (McCrory et al., 2017). Metabolic and structural changes within the brain that have not returned to homeostasis are correlates of the clinical presentation of concussion (Giza & Hovda, 2014; Kou et al., 2010). Sequelae of concussion are heterogeneous in nature and generally include cognitive (e.g., memory and processing speed), physical (e.g., headache and vestibular), and psychological (e.g., depression and anxiety) symptoms (Lannsjo, af Geijerstam, Johansson, Bring, & Borg, 2009). These may be a direct result of neurological injury or produced by a more general psychological response to injury, as several authors have described the similarity of mTBI to other injury groups in this way (G. A. Bloom, Horton, McCrory, & Johnston, 2004; Moran et al., 2012).

Due to high-profile cases in professional sports and increased media attention, there is growing recognition of the importance of brain injury in youth sports. The Centers for Disease Control and Prevention estimate 3.8 million sports-related traumatic brain injuries occur annually in the United States, with the majority of cases classified as mild in severity (Langlois, Rutland-Brown, & Wald, 2006). Sports-related concussion (SRC) and other forms of mTBI have become a major focus of media attention in recent years as a result of human, neuroimaging, and laboratory research suggesting even mild injuries are capable of producing neurobehavioral consequences (Shrey, Griesbach, & Giza, 2011). SRC comprise approximately 9% of all high school sport-related injuries and approximately 20% of all mTBIs (Gessel, Fields, Collins, Dick, & Comstock, 2007; Sosin, Sniezek, & Thurman, 1996).

As of January 2014, all states had passed legislation requiring student athletes to be removed from play until medically cleared (Kreck, 2014). Several consensus-based guidelines aid in the recognition and management of adolescents who sustain sport-related head injuries (Giza & Hovda, 2014; Harmon et al., 2013; McCrory et al., 2017). Despite these efforts, there are currently few studies of treatments or outcomes in this population. In part due to the non-specific nature of concussion symptoms, student athlete injuries may not be detected by coaches or fellow teammates following an injury and return to competition before they have fully recovered. This is hypothesized to increase risk for further injury as a result of decreased neuroplasticity, cognitive sequelae including inattention, and increased neuroinflammation (Griesbach, Gomez-Pinilla, & Hovda, 2004; Longhi et al., 2005; Piao et al., 2013). Return-to-play (RTP) decisions are critical to adolescents' health, as returning to activities prematurely can exacerbate concussion symptoms, increase the risk of sustaining another concussion, and place the student-athlete at risk for more severe and persisting deficits associated with a rare but life-threatening condition known as second impact syndrome (Cantu & Gean, 2010).

In the school-aged and adolescent populations, lingering concussion symptoms can impair academic, social, and emotional functioning (McCrory et al., 2017). Protracted recovery and the associated withdrawal from home, school, and social settings may initiate a self-reinforcing cycle of symptoms (DiFazio, Silverberg, Kirkwood, Bernier, & Iverson, 2016).

Emotional problems such as depression, anxiety, and irritability frequently occur following concussion and can interfere with academic performance due to potentially reduced concentration and processing speed, inattention, or impulse control problems. Following a mTBI, these difficulties can contribute to inattention during classroom lectures, difficulty to read assignments, diminished ability to recall previously learned information, decreased capacity to concentrate and complete assigned work, inability to complete tests during the normal scheduled timeframe, and sensitivity to artificial lighting or media devices used for class instruction (Halstead et al., 2013). When symptoms linger for several weeks, the student-athlete is even more likely to fall behind academically. By the time symptoms resolve, particularly for adolescents where the recovery period is extended, the student-athlete may be required to catch up on fundamental learning principles while his or her peers have moved on to more advanced material.

Although much effort goes into evaluating diagnostic measures for mTBI, at present there is limited evidence available to aid in the identification of adolescents at risk for more severe and complicated recovery. With regard to youth, such findings may be of particular relevance to protect the developing brain. The body of research examining short- and long-term sport concussion outcomes has predominantly covered high school and collegiate athletes, so little is known about recovery specifically in school-aged children. Emerging literature has suggested various factors may predict the course of recovery following sports concussion including nature of the injury itself, comorbidities, and psychological functioning, but it still remains difficult to predict recovery outcomes particularly for younger athletes.

A less often examined facet of concussion presentation is emotional functioning, which has particular significance to youth given their rapidly developing brain systems to manage emotions. An examination of the literature on psychological sequelae of sports concussion has not yet been done and is necessary in order to better characterize the expected course from the standpoint of behavioral health. Further, this information would serve to inform predictions regarding the impact of psychological dysfunction following sports concussion in youth. Emotional or behavioral dysfunction following concussion may be a key to identifying athletes at risk of worse outcomes, but this has not yet been explored in a prospective analysis. Evidence for the use of tools such as mood or sleep screeners in routine concussion assessment would first be needed before altering clinical care.

STUDY DESIGN

Though emerging findings suggest injury and patient characteristics may be associated with a longer recovery time following concussion, few studies have examined psychological and social factors, particularly in youth athletes. To this end, the aim of the current project is twofold: **(1)** conduct a review of the literature on psychological and social outcomes following concussion in school-aged children and adolescents, with an emphasis on sports-related injuries, and **(2)** use novel data to identify predictors of recovery from concussion in student athletes. The proposed project aligns with the Research Training Guidebook's dissertation path "Option 3" and will culminate in two related first-authored journal articles, a literature review (Chapter Two) and a report of related original research (Chapter Three).

To date, no single publication has offered a comprehensive synthesis of the documented psychological and social impacts of mTBI relevant to athletes in the developmental stages of childhood and adolescence. A review of this literature serves to best synthesize the current knowledge base, including considerations for clinicians and researchers alike. It also serves to identify some of the gaps in the literature, which could be addressed by future studies. MEDLINE and PsycINFO databases were queried using relevant search terms and controlled vocabulary, and 604 articles were returned (summarized in Table 1). All titles and abstracts were scanned, and full texts of potentially relevant studies were obtained. Each article was read to determine whether it met inclusion criteria for the review, as follows: **(a)** participants with mild TBI/concussion; **(b)** pediatric, adolescent, or young adult population, or the article included analyses for age; **(c)** outcome variable of post-injury psychological or social issues. In addition, reference lists of included studies were examined for any potentially relevant articles not already captured. Studies gathered during literature review primarily covered the domains of disrupted social/emotional functioning, behavioral problems, academic difficulties, sleep disturbance, headache and pain, and reduced quality of life, with descriptions organized as such in Chapter Two. Descriptions of psychological and social sequelae of mTBI in our literature review emphasized sport-specific concussion literature first, then expanded to include mTBI of heterogeneous etiologies as applicable. Our formal search confirmed expectations that only a small proportion of studies focus specifically on sport-related concussion in youth samples and further highlighted the need for additional studies within this population.

This review additionally aided in creation of hypotheses for the examination of the influence psychological factors among others play in outcomes for concussed student athletes. This utilized a prospective study of concussion recovery in participating North Texas outpatient concussion clinics. Data captured included medical record review as well as self-report of acute symptomatology, psychiatric/medical history, and injury/recovery characteristics. Nearly 400 enrolled subjects study met selection criteria. These included full-time students, aged 12-18, who presented within 14 days of sport-related concussion. At the time of study, a follow-up visit had been completed by 80% of selected participants.

CHAPTER TWO

A Review of Psychological and Social Sequelae of Sports-Related Concussion in School-Aged Children and Adolescents

INTRODUCTION

According to the 2017 Concussion in Sport Group (CISG) consensus statement, a sport-related concussion (SRC) is defined as “a traumatic brain injury induced by biomechanical forces…that may or may not result in a loss of consciousness” and “typically results in the rapid onset of short-lived impairment of neurological function…however, in some cases symptoms may be prolonged” (McCrory et al., 2017, p. 2). There are 173,285 cases of pediatric SRC seen annually in U.S. emergency departments (Centers for Disease Control and Prevention, 2011). The rate of seeking care following SRC has increased in recent years, although the actual incidence of concussion is unknown and likely to be higher than recorded numbers.

SRC, by definition, produces at least short-term neurological symptoms that interfere with functioning. The resulting impairments may be distressing to young athletes and their families. These symptoms are neurobehavioral in nature and can be placed into physical, emotional, and cognitive categories (Ayr, Yeates, Taylor, & Browne, 2009; Heyer et al., 2016; Teel, Marshall, Shankar, McCrea, & Guskiewicz, 2017). In a prospective study of pediatric mTBI (n = 105), the most common postconcussive symptoms after accounting for baseline levels were fatigue (79%), “more emotional” (60%), irritability (58%), and headache (58%) (Barlow et al., 2010). Other commonly reported SRC symptoms include dizziness, difficulty concentrating, vision changes, noise or light sensitivity, and fatigue (Meehan, d'Hemecourt, & Comstock, 2010). Identification of SRC remains difficult in that it may not result in any observable signs;

rather, it is often an “invisible injury” with symptoms that can overlap with typical psychological responses to injury (G. A. Bloom et al., 2004, p. 519).

Whereas concussion symptoms generally resolve within a few days to weeks, some experience lingering symptoms (i.e., post-concussion syndrome or PCS) that may continue interfering with daily functioning. An estimated 14-20% of children will experience postconcussive symptoms that persist beyond three months (Barlow et al., 2010; Ponsford et al., 2001; Taylor et al., 2010), and these children are more likely to have premorbid family or psychological problems (Ponsford et al., 2001). Interestingly, Taylor et al. (2015) reported clinically significant symptomatology, including mood or behavior problems, remained in 12% of their mTBI sample (n = 176, age 8-15) by 12 months post-injury.

Despite a proliferation of research on the cognitive outcomes after mTBI in children, there are many unanswered questions about psychosocial outcomes. For young athletes in particular, routine physical activity and social contact with teammates are often restricted as part of symptom management. In addition, the acute sequelae of concussion (e.g. headaches and reduced concentration) which can interfere with their daily routines at home and school. A recent systematic review of 30 studies on the psychiatric, psychological, and behavioral sequelae after mTBI from various types of traumatic injuries (sport and non-sport) indicated that although more attention is given to physical symptoms, there is evidence for a psychiatric component to recovery from mTBI (Emery et al., 2016). More specifically, there was support for elevated psychological symptom ratings in children following mTBI compared to healthy controls, which generally resolved over time. Despite careful study selection, the authors noted that inadequate control groups and methodological differences often obscured findings. There remains a paucity of research aimed at investigating the short-term and persistent emotional and behavioral outcomes of children who experience mTBI, particularly in the context of sports-related injuries (see V. Anderson et al., 2009 for a discussion).

Given the potentially deleterious consequences of untreated emotional and behavioral problems in school-aged children and adolescents, a better understanding of psychological and social sequelae from SRC is needed. Covassin, Elbin, Beidler, Lafevor, and Kontos (2017) recently reviewed the handful of studies examining post-SRC emotional and coping challenges of predominantly high school and collegiate athletes. Their review provided clear evidence that SRC in adolescents was associated with a disturbance (albeit temporary) in mood as reported by both adolescents and their parents. More specifically, a connection emerged between post-injury anxiety, social support, and protracted recovery. Maladaptive coping, as measured by a brief self-report inventory, was found more frequently in student athletes following SRC than for those with orthopedic injuries. Less is known about the emotional challenges in younger children, which in the context of the developing brain may be critical to study, particularly given that school-aged children are at elevated risk for negative outcomes (Barlow et al., 2010).

Our aim was to consolidate and summarize the body of research that has investigated psychological/social sequelae of SRC in school-aged children and adolescents. We anticipated a small proportion of TBI studies focusing specifically on SRC in youth samples (summarized in Table 2), which further highlights the need for additional studies within this population. Sport-specific concussion literature was first emphasized, then expansion took place to include mTBI of heterogeneous etiologies as applicable. This review does not address cognitive symptoms following injury, as this has been described elsewhere (e.g., Karr, Areshenkoff, & Garcia-Barrera, 2014); rather, the emphasis is on psychological and social outcomes.

Descriptions of studies related to psychological and social sequelae of SRC gathered during the literature review were organized into the following domains: **(i)** social/emotional functioning, **(ii)** behavioral problems, **(iii)** academic difficulties, **(iv)** sleep disturbance, **(v)** headache and pain, and **(vi)** reduced quality of life. We elected to include academic outcomes in this review because of the prominence of the school environment in the lives of children and adolescents. Although sleep disturbance and headache are physical in nature, we have included them as sections given these symptoms are common to concussion and have significant potential to influence academic and psychosocial functioning. Additionally, this review includes investigations of quality of life following SRC, as it dovetails with psychosocial wellbeing. A summary of these factors, which may impact post-injury behavioral, emotional, and social functioning, has not been published specific to pediatric SRC. Given that the research on psychological and social outcomes following mTBI in children is limited, recommendations for future research are included. Specific risk factors for outcomes following mTBI is beyond the scope of this review and has recently been reviewed elsewhere (Iverson et al., 2017).

EMOTIONAL AND SOCIAL DYSFUNCTION

Changes in mood after SRC have been well documented, including the suggestion that the biochemical cascade of SRC may, at least temporarily, directly disrupt mood state (Mainwaring, Hutchison, Bisschop, Comper, & Richards, 2010). In addition, symptoms of SRC, such as reduced concentration, headaches, and sleep disturbance may negatively impact activities in daily life and produce stress, compounding and/or producing emotional disturbances. Specifically in athletes, activity restrictions after concussion may cause further frustration and worry due to reduced contact with teammates, restricted exercise, worry about the future, and limited participation in the sport that is important to personal identity (Meehan, 2011). With reduction in social engagement and sports involvement, athletes may be at particular risk for negative changes in social and emotional functioning following concussion. Mood symptoms increase following mTBI compared to orthopedic injury (Luis & Mittenberg, 2002; Mainwaring et al., 2010; O'Connor et al., 2012), implicating a neurobiological impact of the brain injury that may be disruptive. Functional imaging findings suggested, for instance, that greater recruitment of frontal lobe systems is present during emotional evaluative processes in concussed athletes with elevated post-injury depression symptoms (Ho, Hall, Noseworthy, & DeMatteo, 2017).

The most recent sports concussion consensus statement of the Concussion In Sport Group (CISG; McCrory et al., 2017), as well as the *Report from the Pediatric Mild Traumatic Brain Injury Guideline Workgroup* (Lumba-Brown et al., 2016), suggest that concerns about emotional well-being after mTBI apply to children and adolescents as well as adults. According to the CDC workgroup, social support after mTBI is critical to children and adolescents' quality of life and needs to be addressed in the management of pediatric mTBI (Lumba-Brown et al., 2016). Further, the 2017 CISG consensus statement specifically suggests that psychological interventions after SRC, including cognitive-behavioral therapy, may be required (McCrory et al., 2017).

Depression

Despite the obvious need to understand whether children and adolescents develop immediate or prolonged emotional disturbance after SRC, very little research was found specific to disturbed mood after SRC in pediatric populations. More commonly, SRC outcome has been examined in high school and college-aged athletes, and few studies specifically examined SRC in younger populations. For example, a prospective longitudinal study of high school and college athletes (n = 75) found that depression levels in the entire sample increased above baseline on the Beck Depression Inventory–II (Beck, Steer, & Brown, 1996) two, seven, and 14 days after concussion and remained higher than baseline for the 14-day study period, although scores were not clinically elevated (Kontos, Covassin, Elbin, & Parker, 2012). Despite higher prevalence of depression in females (Kessler, 2003), no sex differences in level of depression were found. Another study of college athletes indicated a significant increase in symptoms of depression on the Profile of Mood States (Grove & Prapavessis, 1992) immediately after concussion (n = 17), with a gradual return to baseline levels by the first week post-concussion (Mainwaring et al., 2010). In this study, however, athletes with orthopedic injuries (n = 7) reported more prolonged levels of depression than concussed athletes, perhaps suggesting emotional dysfunction may also be triggered by generalized injury factors.

Inferences about mood disturbance in school-age children and adolescents after SRC can be informed by the general research on psychological and behavioral outcomes following mTBI. Luis and Mittenberg (2002) found children ages six to 15 who were hospitalized for mTBIs of mixed etiologies (i.e., motor vehicle accident, fall, sports injury) were over nine times more likely to have a new onset mood diagnosis at 6 months post-injury compared to orthopedic controls of skeletal fractures without head trauma. Hawley, Ward, Magnay, and Long (2004) found higher levels of mood swings and withdrawal, but not depression specifically, in school-aged children approximately 2 years post-concussion compared to age- and sex-matched healthy controls. In a separate study comparing depression symptoms at two years after mTBI and arm injury (O'Connor et al., 2012), no significant differences were found across time points (3, 12, and 24 months) in depression symptoms, though criteria for major depressive disorder were met by a larger proportion of patients with uncomplicated mTBI (4-6% across time points vs. 0-3% in controls). Although not isolated to SRC, these conflicting results suggest that more research is needed to determine under what conditions depression manifests after SRC and what factors are associated with greater vulnerability.

Anxiety

Anxiety-related symptoms have been seldom explored following pediatric SRC, and current literature involving mTBI due to other causes may provide guidance. Overall, anxiety was noted as a factor in childhood mTBI recovery across all studies reviewed. A study by Max, Lopez, et al. (2015) showed approximately 10% of children age five to 14 with a mTBI (n = 63) developed a new-onset anxiety disorder within a year of injury. Further, this study suggested that younger age at injury and premorbid anxiety disorder increased the likelihood of post-injury anxiety disorder diagnosis. Another investigation of 42 subjects found concussed children were over four times more likely to have a new-onset anxiety diagnosis within 6-months of injury compared to orthopedic controls (Luis & Mittenberg, 2002); however, anxiety symptom levels were comparable in the mTBI and orthopedic injury groups one and two years later (Hawley, 2003; Hawley et al., 2004). To explain elevated levels of anxiety following injury, Wood, O'Hagan, Williams, McCabe, and Chadwick (2014) found anxiety sensitivity and alexithymia to be mediators for psychological distress, specifically anxiety and depression symptoms, following mTBI resulting from falls or vehicle accidents. Patients with higher levels of anxiety sensitivity and alexithymia, as measured by the State-Trait Anxiety Inventory, were not only more likely to experience higher levels of psychological distress post-injury, but also more likely to report persistent concussion symptoms compared to demographically-matched healthy controls (Wood et al., 2014).

These findings suggest anxiety plays a significant role in recovery post-concussion acutely, and for some, prolongedly. With regard to student athletes, the subsequent restrictions from sport, a significant source of socialization and identity formation, might present a different challenge than that confronted by children experiencing non-sport injuries. Thus, further research evaluating anxiety-related symptoms following SRC would aid in understanding how young athletes may be impacted differently from the general pediatric population.

Social Functioning

Empirical evidence for the effects of SRC upon children's social relationships or development of social competence is lacking. It could be that prolonged disruption in a concussed athlete's reintegration with his or her classmates and teammates might temporarily interfere with social relationships at a critical time in personal development. In fact, a consensus opinion from experts based upon "extrapolated evidence" (Lumba-Brown et al., 2016, p. 68) advises providing social support (including emotional, informational, instrumental, and appraisal) after mTBI based upon the evidence that social support after TBI assists in improvement in quality of life and physical health. In the absence of specific research on SRC, however, this area of inquiry may be informed by studies of social competence in children with mTBI of other etiologies. V. Anderson et al. (2013) assessed social competence, as measured by caregiver report on the Adaptive Behavior Assessment System-II (Harrison & Oakland, 2003), at 6 months in children who experienced TBIs of varying severity and etiology. Their mTBI group (n = 60) did not display social adjustment problems at 6 months post-injury, but at 2 years the mTBI group was more impaired than typically developing controls (V. Anderson et al., 2017). The mTBI group displayed the poorest social competence compared with not only uninjured controls (n = 43), but also the moderate/severe TBI group (n = 33) (V. Anderson et al., 2013). These authors posited that the mTBI group may experience greater difficulty because of the lower amount of support typically provided to children with mild brain injury compared with more severe injury. This fits with the concept of mTBI as an “invisible injury” in adults as well, wherein neurobehavioral changes may go unnoticed by others yet may pose challenges to the individuals experiencing the problems (Song et al., 2018). These findings attest to the need for further investigation of the effects of SRC upon social functioning of school-age athletes in order to understand their needs and provide appropriate support and intervention.

BEHAVIORAL PROBLEMS

There is a dearth of studies investigating behavioral difficulties following pediatric mTBI in general, and to our knowledge, none have directly addressed youth SRC. In an examination of a New Zealand birth cohort followed until age 16, McKinlay, Grace, Horwood, Fergusson, and MacFarlane (2009) identified that children with a history of mTBI during preschool years were at greater risk for attention-deficit/hyperactivity disorder, conduct disorder or oppositional defiant disorder, and mood disorder during adolescence. This negative outcome was posited to be attributable to a disruption in behavioral skill acquisition (whether neurobiologically or psychosocially) during a critical period in the child’s development (Kirkwood, Yeates, & Wilson, 2006).

An investigation of complicated mild to moderate TBI groups carried out by Karver, Kurowski, et al. (2014) assessed parent ratings of child behavior problems and use of behavioral therapy or counseling services in 47 children with complicated mild or moderate TBI and 74 children with orthopedic injuries. At 18 months post-injury, a significantly greater proportion of children with mild-to-moderate TBI (44%) had clinically-elevated behavior ratings than orthopedic controls (44% and 16%, respectively). Rates were similar at extended follow-up (mean of 38 months post-injury), with 46% and 28% of the respective groups demonstrating clinical elevations.

Together, the studies above suggest that some children experience ongoing behavioral issues following mTBI (Karver, Wade, et al., 2014; McKinlay et al., 2009). Taylor et al. (2015) found parent ratings of behavioral problems including delinquency and aggression were greater for children (aged 8-15) with mTBI at 1 year following injury compared to orthopedic controls. Interestingly, an age-related effect was described such that these findings only applied to the younger participants (mean age of 10) in their sample and were also not reflected in teacher ratings of child behavior at any age.

Thus far, a clear understanding of the relationship between SRC and post-concussive behavioral symptoms remains elusive. Conclusions along these lines from more general pediatric mTBI studies have also been hampered by a variety of methodological differences and limitations. These include small sample size, reliance on parent report, issues with premorbid psychiatric or behavioral concerns, lack of differentiation between TBI classification in analyses, and heterogeneous TBI severity. Future studies will need to be conducted with larger samples with attention to aspects of premorbid functioning to clarify these relationships, as has been done in adult, and to some extent pediatric samples, in the moderate/severe TBI literature (e.g., Schwartz et al., 2003).

ACADEMIC DIFFICULTIES

While studies of specific academic difficulties following pediatric mTBI are limited, recent literature has explored the potential effects of pediatric SRC on school-related functioning. Common symptoms of SRC such as headache, dizziness, sensory sensitivities, concentration difficulties, and sleep disturbance, have negative implications in the school environment including problems with sustaining concentration, using academic resources, navigating school environments, and learning new material (Halstead et al., 2013). Factors that have been most associated with return-to-learn (RTL) issues after SRC include severity of concussion and time to recovery (Baker et al., 2015).

Several recent studies have investigated the importance of timing of RTL following pediatric SRC. A recent retrospective study of SRC found that for 45% of the 170 concussions examined, the student-athlete returned to school “too soon” after concussion, as determined by physician chart review, resulting in a recurrence or worsening of symptoms (Carson et al., 2014). In their sample, clearance for RTP in elementary school students was an average 17 days post-injury, significantly shorter than the mean of 25 days for high school students. Additionally, a recent prospective study used daily symptom reports to examine the relationship between school attendance and concussion symptoms in adolescents after SRC, suggesting that too many hours of school after a concussion may exacerbate symptoms (Makki et al., 2016). Furthermore, student athletes who limited cognitive activity associated with academic environments acutely post-injury were at reduced risk for prolonged SRC (Brown et al., 2014).

To our knowledge, no studies have been conducted on the relationship between difficulties with specific academic subjects (e.g., math, reading, etc.) and SRC. In the context of a neuroimaging study to assess the integrity of white matter tracts implicated in mathematical skills, Van Beek, Ghesquiere, Lagae, and De Smedt (2015) found children with mTBI tended to perform poorly compared to healthy controls on rapid assessment of the presence of small numbers of objects (subitizing), processing of non-symbolic large number quantities, and procedural problem solving. In another study of mathematical difficulties in 20 children with mTBI, Van Beek, Ghesquiere, De Smedt, and Lagae (2015) found that children with mTBI were not as accurate in solving mathematical equations compared to healthy controls. Future research on performance in specific academic subjects after SRC will be needed to determine if concussed athletes might require special classroom accommodations for particular subjects. Moreover, clinicians will need to identify such difficulties and parents and teachers may need to manage academic expectations.

The critical topic of cognitive exertion in the school setting after concussion also requires further study. Academic tasks that are particularly challenging may stress an already taxed brain; therefore, it will be important for medical and school staff to determine when a concussed student should return to academic activities and what level of cognitive exertion is appropriate for the student. Athletic guidelines encourage rest and a graduated, step-by-step return to normal academic activities (McCrory et al., 2017), based on the idea that resuming activities too soon may exacerbate symptoms and potentially delay recovery. The optimal period of rest for each individual is unknown, however. Recent studies suggest that resolution of concussion symptoms in adolescents may be slower with an extended period of strict rest, implying that both too little and too much restriction from participation in academic activities may impact recovery (Buckley, Munkasy, & Clouse, 2016; Schneider et al., 2017; D. G. Thomas, Apps, Hoffmann, McCrea, & Hammeke, 2015). Symptom monitoring in the school setting is critical, as school concerns have been reported by actively symptomatic students and their parents following heterogeneous pediatric mTBI, with greater symptom severity associated with more school-related problems and worse academic effects (Ransom et al., 2015). This relationship held for both parent- and adolescent- symptom ratings, but not for self-report in younger students aged 10-12. More research is needed to elucidate academic difficulties specific to pediatric SRC, using both self- and informant-reports particularly in younger students.

SLEEP DISTURBANCE

Sleep disturbance is a significant consequence of pediatric SRC, as alterations in a patient's normal sleeping pattern often develop in the days or weeks following a concussion and may remain throughout the recovery course (Eisenberg, Meehan, & Mannix, 2014). Nearly a third of adolescent patients self-report excessive sleep or trouble falling asleep following SRC Meehan et al. (2010). Collegiate and professional athletes report greater subjective sleep disturbance following concussion compared to both non-injured and orthopedically-injured controls (Gosselin et al., 2009), matching the pediatric mTBI literature (Milroy, Dorris, & McMillan, 2008; Tham, Fales, & Palermo, 2015). In contrast to subjective report, findings regarding sleep disturbance from studies using actigraphy and polysomnography methodology have been inconsistent within the pediatric mTBI literature. Gosselin et al. (2009) did not find significant differences in polysomnographic sleep activity when examining athletes following SRC compared to healthy athletes from noncontract sports. However, other mTBI studies in adolescents have detected sleep problems using objective measurements in comparison with controls (Kaufman et al., 2001; Tham et al., 2015).

Inadequate sleep may impact cognition and has been associated with depression, fatigue, and mental fogginess not only in concussed athletes, but even in healthy adolescent samples (Kostyun, Milewski, & Hafeez, 2015). Neurocognitive function during recovery from SRC may be particularly affected by disrupted sleep; Kostyun et al. (2015) found excessive sleep (longer than nine hours) the night prior to postconcussion testing was associated with reduced performance on tasks of visual memory, visual motor speed, and reaction time. Sleep difficulties have also been associated with poorer functional, social, and emotional outcomes in the general pediatric mTBI literature (Albicini, Lee, & McKinlay, 2016; Chan & Feinstein, 2015), although fewer studies with specific SRC samples have been conducted. As in older individuals, changes in a child's normal sleeping patterns following SRC may hinder recovery and worsen other symptoms including headache, emotional lability, and academic functioning (Kostyun, 2015; Meehan et al., 2010). Consequently, clinicians must be able to discern how patients may be affected by changes in sleep following concussion and be equipped to treat sleep-related difficulties, which is made more difficult because sleep patterns change throughout childhood and adolescence.

Knowledge of the etiology of disruptive sleep following pediatric mTBI remains limited. Excessive sleep has been hypothesized to represent the optimal environment needed for the brain to restore its normal neurometabolic homeostasis or be a protective mechanism from overexertion of cognitive activities (Khoury et al., 2013; Kostyun et al., 2015), although too much sleep may also be associated with some symptoms. Along these lines, rest is one of the most common behavioral prescriptions following mTBI, and while some rest after injury appears to be beneficial, mounting evidence suggests that too much rest can be associated with prolonged symptoms (e.g. see review by Schneider et al., 2017). Thus, future research should focus on investigating the etiology of sleep disturbance to further understand its relationship with other symptoms and ultimate role in outcomes following pediatric SRC, as well as determining the appropriate “dose” of rest for optimal recovery.

HEADACHE AND PAIN

Pain can have a negative impact on daily activities, mental health, employment status, sleep, and personal relationships (McCarberg, Nicholson, Todd, Palmer, & Penles, 2008). Specifically following SRC in adolescents, complaints of acute and chronic headache are among the most frequent somatic complaints, occurring in more than 90% of concussed high school athletes (Meehan et al., 2010). Headache is a symptom that commonly co-occurs with other physical, emotional, and cognitive complaints following concussion. For example, high-school students with SRC reporting headache within seven days of injury more frequently endorse other concussion symptoms compared to those without headache (Collins et al., 2003). Additionally, for many adolescent athletes, headache is not only a key symptom that in combination with other on-field indications leads to a suspected or diagnosed concussion, but it also serves as an important determining factor in players’ RTP (Lau, Collins, & Lovell, 2011).

While more research is needed on headache symptoms following pediatric SRC, the general pediatric mTBI literature has described varying rates of headache. For example, in an emergency department sample of children and adolescents with mTBI (n = 406), headache was present in 31% at 3 months (Babcock et al., 2013). Barlow et al. (2010) found that when compared to an extracranial trauma group, children who experienced mTBI were more likely to experience headache at 3 months post-injury. Blume et al. (2012) found elevated rates of post-injury headache in children with mTBI treated at emergency departments compared to children treated for arm fracture (43% of 402 and 26% of 122, respectively), based on both parent and self-report. In contrast, Kuczynski, Crawford, Bodell, Dewey, and Barlow (2013) found that among children reporting to an emergency department following mTBI (n = 670), only 11% of participants experienced post-traumatic headaches initially, with reduction to 8% at three-month follow-up. In a representative U.S. sample (n = 6,483), Nakamura, Cui, Lateef, Nelson, and Merikangas (2012) found that caregiver report of headache symptoms in adolescents was lower than self-reported symptoms of headache; adolescents were also more likely to endorse chronic headaches, longer-lasting headaches, and experiencing photophobia and phonophobia, as compared to parent report of symptoms. This variability in rates of postconcussive headache are potentially due to differences in communication of symptoms. While more research is needed to investigate the impact that headache symptoms have in children following SRC, these findings suggest that it may be beneficial to assess headache symptoms via parent- and child-report of symptoms to best assess the severity, impact, and treatment of headaches in this population.

Despite headache being the most frequent pain type after pediatric SRC (Meehan et al., 2010), no studies have investigated other types of chronic pain following pediatric SRC or in the general pediatric mTBI literature. However, adult mTBI literature suggests that neck and shoulder, limb, or back pain are also common in injuries associated with mTBI. For example, Khoury et al. (2013) demonstrated widespread pain reported in a young adult mTBI sample (n = 24) at one month including the head, neck, and lower back, and less commonly leg and feet. Importantly, this study also found that chronic pain was associated with poor sleep vs. asymptomatic controls (n = 18), suggesting the importance of postconcussive pain assessment and management. Additionally, higher risk of developing chronic pain has been associated with initial pain levels post-mTBI. Research is needed to investigate the presence of chronic widespread pain following pediatric SRC and explore whether headache is a risk factor for chronic widespread pain or whether they are separate processes with different time courses (Ofek & Defrin, 2007). Additionally, future research should investigate the transition of acute post-mTBI pain to chronic pain following pediatric SRC, as it likely involves complex interactions between neurobiological and psychosocial factors similar to what is seen in more severe TBI populations (Young Casey, Greenberg, Nicassio, Harpin, & Hubbard, 2008).

QUALITY OF LIFE

Quality of life (QOL) is a construct that involves subjective evaluation of satisfaction with one’s life and activities of daily living, including the domains of physical, mental, and social well-being. Health-related QOL addresses the impact of health on well-being. General QOL, as well as health-related QOL, may be negatively affected by concussion, including SRC, although this has been sparsely investigated in pediatric populations. Although QOL is less specific than the other domains we have reviewed in relation to pediatric SRC, it represents a broader and more personal view of a child's functioning and well-being and can serve as a general outcome variable in studies of mediating and moderating factors that may affect overall adjustment and functioning after SRC.

A recent systematic review of health-related QOL following pediatric mTBI had mixed findings, with several studies documenting marginal or no significant post-injury changes in QOL (Fineblit, Selci, Loewen, Ellis, & Russell, 2016). In a sample of school-aged children (n = 130), V. Anderson, Godfrey, Rosenfeld, and Catroppa (2012) reported no significant changes at 6 months post-injury when compared to pre-injury estimates collected at baseline using the parent reported Child Health Questionnaire (CHQ; Landgraf et al., 1998). Pieper and Garvan (2014) collected child and parent Pediatric QOL Inventory (PedsQL) ratings from 40 subjects at 1, 3, 6, and 12 months following mTBI. These authors found acute ratings did not differ from preinjury estimates, with the exception of parent-reported physical health problems at 6 months, which resolved by 12 months. In pediatric patients (n = 329), poor health-related QOL (i.e., parent or adolescent self-report PedsQL score >15) was found in 11% of the sample at 3 months and 13% at 12 months following concussion (Zonfrillo et al., 2014). In a study examining both complicated and uncomplicated pediatric mTBI samples (n = 616), Rivara et al. (2011) reported that although PedsQL scores were reduced at 3, 12, and 24 months compared to baseline, these reductions were similar to those seen in orthopedic controls.

As noted above, concussion symptoms are typically transient in nature for most children (McCrory et al., 2017), and as such, may not affect QOL. However, declines in QOL are observed to persist following pediatric mTBI in some cases even after reported symptom resolution (Novak et al., 2016), with symptom burden impacting the decline (Russell et al., 2017). Lower physical and cognitive ratings on the PedsQL acutely following SRC was associated with greater symptom burden and longer recovery times in 1,134 adolescent athletes (Houston, Bay, & Valovich McLeod, 2016; Russell et al., 2017). Using semi-structured interviews of seven adolescent student-athletes and caregivers following SRC, Iadevaia, Roiger, and Zwart (2015) identified a significant impact to daily life rendered by postconcussive symptoms including on emotions, school attendance and social engagement. Review of general pediatric mTBI literature reveals that declines in QOL following pediatric mTBI are similar to those observed with orthopedic injuries (Moran et al., 2012; K. O. Yeates, Kaizar, et al., 2012). Moran et al. (2012) identified a relationship between postconcussive symptoms and reduced parent ratings of health-related QOL via the CHQ; however, this relationship held for both mTBI (n = 186) and orthopedically-injured groups (n = 99). Specifically, physical symptoms were associated with reduced physical QOL, and symptoms from both the physical and cognitive domains predicted reduced psychosocial QOL (Moran et al., 2012). After controlling for estimated baseline symptom in this sample, a reliable change in both cognitive and somatic postconcussive symptoms was more likely in the mTBI than the orthopedically-injured group (K. O. Yeates, Kaizar, et al., 2012).

There is some evidence for declines in QOL following adolescent SRC, though replication in this population is needed. Further, these declines may not differ from those found following pediatric orthopedic injuries (Moran et al., 2012; K. O. Yeates, Kaizar, et al., 2012). Given the association between QOL and symptom burden (Russell et al., 2017), QOL issues may be more common in children and adolescents who are hospitalized or present to emergency departments following mTBI, as these injuries may be higher in severity. Further, in order to better understand the clinical utility of patient reports of QOL following injury, further comparison of child, parent, and observer report in relation to outcomes may be useful.

DISCUSSION

Empirical investigation of the consequences of SRC has increased dramatically in the past decade with much attention on professional and collegiate athletes. Because more emphasis has been placed on resolution of cognitive symptoms, this review investigated psychological and social implications following concussion specific to school-aged and adolescent student athletes. Table 2 summarizes studies that specifically examined pediatric SRC. Above, we included discussion of relevant general mTBI studies, as they provide a basis for understanding possible outcomes of SRC where little else is available. The scope of our review included social and emotional functioning, behavioral problems, academic difficulties, sleep disturbances, headache and pain, and quality of life.

Our conclusions are in agreement with the opinions of Emery et al. (2016) that a solid understanding of both the short-term and long-term emotional and behavioral sequelae of SRC has yet to be achieved. As research about the psychosocial outcomes of SRC expands, clinicians will be able to anticipate the psychosocial needs of student athletes more accurately after concussion. Difficulties can therefore be identified more quickly, and perhaps prolonged affective and behavioral disturbances can be avoided. In order to provide these services to student athletes, more complete knowledge of the psychosocial outcomes and risk factors related to SRC in children and adolescents is needed. For instance, the development of anxiety after concussion has been more clearly documented than depression but may not receive as much clinical attention. Despite not reaching the clinical threshold of diagnosis, behavioral problems such as defiance and aggression occur at a higher rate in children and adolescents following mTBI. There is also a paucity of information about the factors related to the development of more prolonged or severe psychological distress and who may be a greater risk.

Children and adolescents spend a good part of their day in school, and school adjustment and performance have important implications for identity development and future academic and even occupational potential. A systematic structured literature review by Davis et al. (2017) related to pediatric athletes' recovery after SRC indicated that academic accommodations are more likely to be provided to concussed athletes if the school has a policy in place and that 35–73% of student athletes needed accommodations. Regarding availability, a large sample of school nurses reported in a survey that only 53% of the 1,027 respondents indicated their school had guidelines for students with concussion (Olympia, Ritter, Brady, & Bramley, 2016). Additionally, in a national sample only 44% of the 995 athletic trainers reported that their school had a policy for return to learning (Kasamatsu, Cleary, Bennett, Howard, & McLeod, 2016).

Academic functioning in the subject areas of math and reading appears to be particularly vulnerable in samples of school-aged children and adolescents (Johnson et al., 2015; Van Beek, Ghesquiere, De Smedt, et al., 2015). Academic tasks may place additional cognitive stress on a brain that is already physiologically challenged following concussion. Therefore, returning to school too early can exacerbate symptoms, creating a downward spiral of dysfunction that can have psychological consequences, a topic that has received insufficient attention in the literature.

The optimal amount of cognitive and physical rest is debated. While some initial rest may be indicated, this should not come at the expense of delaying successful reintegration. It is important to consider when and how concussion symptoms might impact academic performance when the child returns to school so that failure can be avoided. Unnecessary academic failure can negatively affect a student athlete's academic standing, potentially interfering with future opportunities such as college admission and scholarships. Moreover, emotional distress and social withdrawal, whether or not accompanied by academic failure, have the potential to weaken interpersonal connections, which are at the heart of identity development, particularly for adolescents.

Future research needs to address certain study design limitations common in studies of mTBI, such as those reviewed in (Macciocchi, Barth, & Littlefield, 1998). In particular, notable heterogeneity in research designs makes conclusions about emotional and behavioral symptoms following SRC difficult. For example, parent, teacher, and self-report of social-emotional and behavioral symptoms is often discrepant (e.g., Smith, 2007); therefore, the informant(s) for conclusions about symptom presentation should be specified. Because parents tend to report more externalizing, observable problem behaviors than do their children, and children tend to report more internalizing symptoms than their parents (Edelbrock, Costello, Dulcan, Conover, & Kala, 1986), discrepancies need to be viewed in this context. Specifically, children with mTBI report more somatic symptoms of concussion than do their parents (e.g., dizziness), but do not report more cognitive symptoms (e.g., trouble paying attention) (Hajek et al., 2011). Furthermore, parents' emotional reactions to their child's difficulties after concussion may influence perceived symptom severity and produce misattribution of symptoms. For example, misattributing the presence of headache to concussion, although headaches had been present prior to the concussion, has the potential to impact data accuracy for the trajectory of recovery from concussion (Brooks et al., 2014). Additionally, the influence of premorbid factors such as preexisting childhood psychiatric disorders or symptoms has been well documented (K. O. Yeates, Taylor, et al., 2012), and family functioning, including perceived family burden and distress, has not been sufficiently studied. Research that controls for these factors is needed.

Research could also be translated into clinical practice by directing efforts toward identifying appropriate accommodations for both acute and prolonged concussion symptoms. The neurobehavioral sequelae of concussion persist for months in some children (Karver et al., 2012; Taylor et al., 2015). Management of potential psychological consequences such as anxiety can range from facilitating support for athletes soon after injury to referrals for behavioral therapies. Furthermore, as with other causes of mTBI, it is important to evaluate whether emotional symptoms are present, particularly because symptoms may not always be recognized as attributable to the concussion. Early responsiveness will potentially mitigate the distress experienced by concussed athletes in the short term and is expected to avert the development of prolonged psychosocial consequences.

CHAPTER THREE

Postconcussive Anxiety, Depression, and Sleep Quality as Predictors of Prolonged Recovery in Adolescent Student Athletes

INTRODUCTION

Recent figures estimate 1.1 to 1.9 million pediatric sports- and recreation-related traumatic brain injuries (TBIs) occur annually within the United States (Bryan, Rowhani-Rahbar, Comstock, Rivara, & Seattle Sports Concussion Research, 2016), though this more conservative figure is likely an underestimate due to misdiagnosed or untreated injuries. When broadening estimates, Langolis and colleagues posit a more inclusive model that contains upwards of 3.8 million total injuries. Within the adolescent population, sports related concussions (SRCs) comprise roughly 9% of high school sport-related injuries, as determined by a nationally representative sample of 4,431 injuries (Gessel et al., 2007).

Concussion sequelae include a myriad of physical, psychological, and cognitive symptoms that are not specific to TBI and occur with relatively high frequency in otherwise healthy individuals. Often U.S. high school athletes report postinjury headaches, dizziness, amnesia, confusion or disorientation, and concentration difficulties as well as drowsiness, irritability, and hyperexcitability, though less commonly (Meehan et al., 2010). With regard to concussion symptom resolution, knowledge surrounding the pattern and time course is unclear. Estimates of concussion recovery vary widely for youth, and while symptoms tend to resolve by an average of seven days (Nelson et al., 2016) some take weeks to months (Henry, Elbin, Collins, Marchetti, & Kontos, 2016; Kerr et al., 2016; Zuckerman, Lee, et al., 2012). Symptoms that persist beyond 3 months postinjury are commonly described as “postconcussive syndrome,” although matched individuals sustaining extracranial trauma have been found to endorse similar rates of postconcussive symptoms at three-months postinjury (Meares et al., 2008).

Recovery from SRC

Evidence-based research on SRC has grown exponentially in the last two decades with widespread interest from the media, laypersons, clinicians, and school professionals. Lingering concussion symptoms can negatively impact adolescents' academic, social, and emotional functioning (McCrory et al., 2017). A recent systematic review by Iverson et al. (2017) summarized the relationship of prolonged recovery following SRC and several risk factors from medical and injury history, including age, sex, previous head injuries, loss of consciousness (LOC), post-traumatic amnesia (PTA) or retrograde amnesia (RA), and postinjury symptoms. However, these relationships did not hold for all studies reviewed. Tables 3 and 4 present an outline of prior support for these risk factors in samples of middle and high school athletes.

Age. Youth are at greatest risk for adverse outcomes such as development of persistent post-concussive symptoms (Covassin, Elbin, Harris, Parker, & Kontos, 2012; Zemek et al., 2016). Compared to adults and pre-adolescents, adolescents report the greatest postconcussive symptom severity (Murdaugh, Ono, Morris, & Burns, 2018). Adolescent athletes demonstrate worse neurocognitive and balance performance postinjury and are symptomatic for longer than adults (Covassin, Elbin, Harris, et al., 2012). Middle and high school athletes have also been reported to experience different durations and patterns of symptom and neurocognitive recovery compared to collegiate athletes (Covassin, Elbin, Larson, & Kontos, 2012; Field, Collins, Lovell, & Maroon, 2003; Zuckerman, Lee, et al., 2012) and their younger peers (Murdaugh, Ono, Morris, et al., 2018).

Biomechanical processes such as decreased neck strength and skull thickness may result in younger individuals sustaining injury with less force (Proctor & Cantu, 2000). However, the young brain is also vulnerable given injury may disrupt crucial developmental changes in structure and function (Keith Owen Yeates & Kirkwood, 2012, p. 79). Adolescents are vulnerable to neurocognitive disruption following injury given the acquisition of skills during this period. Processes such as attention, impulse control, and cognitive flexibility are in a critical period of development for youth younger than 12 years old and continue to develop after the age of 12 (P. Anderson, 2002). Adolescence is a unique period of development in which environmental demands and autonomy are beginning to increase. In addition to abilities such as behavioral control, an athlete's day-to-day environment such as academic and social activities can impact attunement to postconcussive symptoms.

Sex. Females tend to experience SRC symptoms for longer (Kostyun & Hafeez, 2015; Miller et al., 2016; Resch, Rach, Walton, & Broshek, 2017; D. J. Thomas et al., 2018), with almost twice the recovery time of adolescent males (Baker et al., 2016; Bock et al., 2015; Stone, Lee, Garrison, Blueitt, & Creed, 2016). Female athletes (aged 10-19) were 1.3 times more likely to be symptomatic across time points in a recent survival analysis (Heyer et al., 2016). In a separate sample of athletes (aged 10-17), females were twice as likely to experience prolonged recovery (D. J. Thomas et al., 2018). Greater declines in neurocognitive performance are seen in female student athletes following injury compared to males (A. C. Colvin et al., 2009; Covassin, Elbin, Harris, et al., 2012). Female student athletes exhibit slower reaction times, lower visual memory performance, and greater symptom burden after concussion (Broshek et al., 2005; Covassin, Elbin, Harris, et al., 2012). However, there are twice as many studies reporting an absence of sex differences in symptom recovery (Baker et al., 2015; Chrisman, Rivara, Schiff, Zhou, & Comstock, 2013; Frommer et al., 2011; Hang, Babcock, Hornung, Ho, & Pomerantz, 2015; Lax et al., 2015; Moor et al., 2015; Morgan et al., 2015; Ono et al., 2016; Terwilliger, Pratson, Vaughan, & Gioia, 2016; Zuckerman, Solomon, et al., 2012), indicating differences are likely small and difficult to detect. Supportive studies adjusted for higher initial levels of symptoms in females (Baker et al., 2016), and were generally larger (e.g., Heyer et al., 2016) with slightly better representation of female participants (e.g., Kostyun & Hafeez, 2015). Non-supporting studies included those with categorical outcome for recovery length (Chrisman et al., 2013; Frommer et al., 2011; Hang et al., 2015), either as a binary outcome (e.g., symptomatic at one week) or time intervals. An outline of support for this relationship is displayed in Table 3.

Multiple etiologies may drive differences in symptom recovery between males and females. Anatomical differences, such as neck strength, may mean injury with less force (Grady, 2010). Other physiological differences such as hormonal systems have also been implicated (Broshek et al., 2005). An overlap with differences in rates of somatization, which is linked to delayed symptom recovery in female adolescents (Root et al., 2016), may also be a contributing factor. In addition, the recovery trajectory of women is likely different in part because women tend to endorse symptoms to a greater degree than men, both at baseline and following injury (Broshek, De Marco, & Freeman, 2015; Covassin, Elbin, Larson, et al., 2012). However, such biases in preinjury symptom reporting have been inconsistently documented in high school athletes (Iverson et al., 2015; Kontos, Elbin, et al., 2012) and likely cannot fully account for postinjury discrepancies.

Multiple concussions. Youth athletes with a previous concussion are more likely to experience prolonged recovery (J. D. Colvin et al., 2013; Morgan et al., 2015; D. J. Thomas et al., 2018). In a national sample of high school football players, having a previous concussion more than doubled the risk for symptoms one week following injury (Chrisman et al., 2013). And, several studies have described elevated symptoms remaining at four weeks (Corwin et al., 2014; Miller et al., 2016; D. J. Thomas et al., 2018). In contrast, Hang et al. (2015) found that young athletes with a prior concussion were more likely to be symptomatic at one- but not four-week follow-up. Contradictory evidence indicating previous concussions pose no threat to subsequent injury recovery more than doubles that which is consistent with this finding (Baker et al., 2015; Barlow et al., 2010; Ellis et al., 2015; Field et al., 2003; Heyer et al., 2016; Lau, Collins, & Lovell, 2012; Mautner, Sussman, Axtman, Al-Farsi, & Al-Adawi, 2015; Moor et al., 2015; Terwilliger et al., 2016). Differences in study design, particularly how concussion history is operationalized, are likely responsible for this outcome. Table 3 has organized the support for this relationship in the adolescent SRC literature.

Even a mild injury to the brain can disrupt neurotransmitter transmission and create neurometabolic vulnerability to increased impairment and prolonged recovery following reinjury. After a repeated concussive event, youth athletes experience protracted return of metabolic functioning to baseline (Vagnozzi et al., 2008), suggesting a cumulative effect of injury. Repetitive head injury poses a more significant threat for children, who are at increased risk for developing “second impact syndrome,” a rare but fatal cerebral edema that occurs after concussion (McCrory, Davis, & Makdissi, 2012).

Injury severity. According to a systematic review of predictors associated with SRC recovery (Iverson et al., 2017), characteristics specific to the severity of injury, such as loss of consciousness and amnesia, may also predict greater recovery time, although literature is mixed (Meehan, Mannix, Stracciolini, Elbin, & Collins, 2013). Athletes with LOC or PTA in the survival analysis mentioned above were 1.2 times more likely to be symptomatic; in contrast, RA was not a significant predictor of recovery (Heyer et al., 2016). In the same national sample of high school concussions, amnesia was a risk factor only for the male players and LOC was not predictive (Chrisman et al., 2013). Bock et al. (2015) examined RTP in adolescents, but LOC and amnesia were non-significant factors. Similarly, Lau, Kontos, Collins, Mucha, and Lovell (2011) did not find LOC to predict protracted recovery in adolescent student athletes. These inconsistent findings may be due to the variety of study designs or perhaps the low frequency with which these events are observed following mTBI.

The most consistent predictor of prolonged recovery following concussion is severity of postconcussive symptoms. At initial clinic visit, athletes reporting a higher symptom burden take longer to recover (Heyer et al., 2016; McCrea et al., 2013; Meehan, Mannix, Monuteaux, Stein, & Bachur, 2014; Miller et al., 2016; D. J. Thomas et al., 2018). High school athletes with lower initial postconcussive symptoms are more likely to reach symptom recovery within a week (Chrisman et al., 2013; Greenhill et al., 2016; Hang et al., 2015). High school football players who were slow to recover were more likely to report a greater number of initial postconcussive symptoms and additionally had poor performance on neurocognitive testing (Iverson, 2007). Three studies have not found greater acute/subacute symptoms to be a risk factor for recovery

(Barlow et al., 2010; Moor et al., 2015; Morgan et al., 2015). Table 4 lists support for the relationship of injury severity characteristics and recovery following adolescent SRC.

Psychological Factors as Prognostic Indicators

A great deal of attention has been given to postinjury symptoms as a whole, despite that postconcussive symptoms are heterogeneous in nature. The symptoms of concussion are nonspecific and overlap with the cognitive, physiological, and emotional symptoms produced by mood and sleep disorders and many other health conditions. Emotional and psychosocial consequences of SRC are important to examine because of the unique impact of an injury on an adolescent's lived experience. Onset of postinjury mood and sleep difficulties can be exacerbated by the psychosocial and emotional disruption to an adolescent's life following injury (Valovich McLeod, Wagner, & Bacon, 2017). Several recent reviews have documented the psychological sequelae of concussion in pediatric and sports populations (Broshek et al., 2015; Covassin et al., 2017; Emery et al., 2016). Their findings indicate problems such as mood disturbances, social isolation, and poor coping are observed after injury (Covassin et al., 2017). When concussion symptoms include concurrent emotional disruption, worse outcomes are observed (Emery et al., 2016). A better understanding of the psychological factors of concussion may aid in better concussion assessment and management (Broshek et al., 2015). These disturbances may be initiated or exacerbated by the neuropathological processes induced by head injury (Shrey et al., 2011).

The development of psychological symptoms in certain individuals following concussion has been described as a risk factor for worse outcomes (Ellis et al., 2015; Murdaugh, Ono, Reisner, & Burns, 2018). Anxiety sensitivity may predispose athletes to focus on physiological symptoms following injury, which may in turn protract recovery time (Hixson, Allen, Williams, & McLeod, 2017). In a recent comparison of collegiate athletes (n = 30), those who experienced a musculoskeletal injury and those with concussion were similar with respect to mood disturbance and anxiety acutely following injury (Turner et al., 2017). Thus, limitation of daily activities following injury likely contributes to psychological symptoms as well. In the pediatric mTBI literature, postinjury depressive symptoms have been associated with headache, sleep issues, academic dysfunction, and reduced quality of life, suggesting that disruptions in other areas of the child's life produces or exacerbates low mood (Kwan, Vo, Noel, & Yeates, 2018). Lastly, there are psychosocial factors specific to the youth athlete involved in injury recovery. Factors such as fear of reinjury, fear of being perceived as weak, and fear of losing a desired role or affiliation with a team complicate SRC recovery (Broshek et al., 2015). These fears may add additional stress to an athlete experiencing postinjury depression and/or anxiety, potentially exacerbating emotional difficulties.

Individuals for whom symptoms persist following SRC or other mTBI have been termed the "miserable minority," (Willer & Leddy, 2006) and are more likely to have preinjury or familial histories of mood disorders (Morgan et al., 2015). Anxiety-related symptoms have not been specifically explored in pediatric SRC. Extrapolated evidence from adults with mTBI and minor non-head injuries, greater anxiety symptoms at one-week postinjury predicted postconcussive symptom exacerbation at three-months, and anxiety levels were associated with premorbid psychiatric illness (Ponsford et al., 2012). Within an outpatient rehabilitation program, lower initial depression scores of patients with mild TBI were significantly associated with improved functional recovery at three-month follow-up (Scott, Strong, Gorter, & Donders, 2016). Anxiety and depression were identified risk factors for increased symptom burden and psychological distress following concussion in a study of university athletes (Weber et al., 2018). Yang and colleagues (2015) found that preinjury depression strongly predicted postinjury ratings of depression and anxiety; premorbid anxiety, however, was not associated with increased postinjury depression or anxiety.

Though much sparser than for adults and with varying study designs, the pediatric literature on postconcussion psychological functioning conveys that greater emotional or sleep disturbances predict worse outcomes. An examination of psychiatric outcomes following pediatric concussion conducted by Ellis et al. (2015) identified that 10% of the 174 athletes experienced a new-onset psychiatric disorder or worsening of a pre-existing psychiatric disorder. This subset with poorer psychiatric outcomes experienced greater postconcussive symptoms across items as well as within the emotional domain (irritability, sadness, nervousness, and feeling more emotional) and were more likely to develop postconcussive syndrome (Ellis et al., 2015). A relationship between attention-deficit/hyperactivity disorder (ADHD) and concussion recovery has not been supported in adolescent athletes (Lau et al., 2012; Mautner et al., 2015; Terwilliger et al., 2016). Sleep disturbances in adolescents have been linked to the development of depression and anxiety (Morse & Garner, 2018), and sleep disturbances following SRC are highly correlated with other postconcussive symptoms (Murdaugh, Ono, Reisner, et al., 2018). Premorbid sleep difficulties predict worse postconcussive neurocognitive performance in adolescents (Sufrinko et al., 2017). A study of adolescents within an outpatient clinic (n = 417) examining the impact of sleep on duration of postconcussive symptoms found that difficulty falling or staying asleep indicated a 3-4 times increased recovery length (Bramley et al., 2017).

Study Aims

SRC remains an elusive injury despite the growth of studies examining this phenomenon. Variability in patterns of individual recovery is poorly understood, particularly for youth athletes. A more comprehensive view of risk factors for prolonged recovery from SRC can assist clinicians, researchers, and athletic trainers alike in identifying at-risk individuals and tailoring effective concussion interventions. Although neurocognitive recovery has been a large focus in the literature, there are reported differences in the subjective and objective symptom presentation of adolescent athletes, compared to youth and adults (Murdaugh, Ono, Morris, et al., 2018). The aim of the present investigation was to examine SRC recovery within a sample of middle and high school students who are homogeneous in terms of biopsychosocial development

Prospective studies in particular are needed to further elucidate best practices in SRC management (Reddy & Collins, 2009). The present investigation used clinician-determined readiness to initiate a RTP protocol, rather than self or informant report. Patients who are asked to retrospectively estimate recovery are subject to recall bias, and the reliability of their self-report is unknown. Moreover, recovery necessarily involves clinical judgment following the evaluation of a qualified practitioner, as symptomatology indicating concussion resolution can vary. For instance, some athletes experience complete absence of symptoms, while for others a return to their premorbid level of symptoms and/or improvement of symptoms may be indicators of recovery. In addition, clinicians can take a more nuanced approach and incorporate aspects of neurocognitive recovery as well as symptom resolution in determining fitness to RTP. This multifaceted approach is more individualized and considers the whole person rather than symptom-free status.

Researchers have started to turn attention specifically to psychological symptoms and the role emotional functioning plays in SRC recovery patterns. Given the dynamic interplay between injury characteristics, physiological factors, and psychosocial functioning, psychological symptoms may be indicative of a worse recovery trajectory. However, the body of literature specifically examining the psychological sequelae of SRC is very small. To our knowledge, no prior studies have examined postinjury psychological symptoms, particularly using validated measures of emotional functioning, as predictors of recovery length in adolescents following SRC.

The current investigation examined postinjury psychological symptoms overlapping with concussion within a sample of adolescent athletes. As described above, several known injury severity indicators have been identified in athlete populations. To this end, analyses in the current study used statistical methods to examine and control for six preinjury predictors: **(i)** sex, **(ii)** prior psychiatric history, **(iii)** prior history of head injury, **(iv)** loss of consciousness, **(v)** post-traumatic amnesia (PTA) or retrograde amnesia (RA), and **(vi)** initial postconcussive symptom severity. While considering the 6 potential premorbid and injury influences, and additionally explored separate models for males and females, three postinjury symptoms of mood and sleep disorders for recovery were additionally examined, for a total of nine predictors: **(vii)** anxiety symptoms, **(viii)** depression symptoms, and **(ix)** sleep quality.

Hypotheses

1. It was hypothesized that male and female athletes would display different concussion recovery functions, with ***greater risk for prolonged symptom resolution in females***. This prediction is based on number of adolescent sport samples that have yielded positive

findings (Bock et al., 2015; Ellis et al., 2015; Heyer et al., 2016; Kostyun & Hafeez, 2015; Stone et al., 2016), which were reviewed above and listed in Box 1.

2. It was hypothesized that preinjury and injury severity characteristics previously associated with recovery from SRC (Iverson et al., 2017) and other mTBI (Keith Owen Yeates & Kirkwood, 2012, p. 125) would be significant predictors of symptom clearance (see Tables 3 and 4). Specifically, the prediction was that ***individuals with a preinjury psychiatric disorder or prior concussion history and those experiencing postinjury LOC, amnesia, or greater postconcussive symptom severity would be at increased risk of being symptomatic***.
3. It was hypothesized ***increased postinjury symptoms of anxiety, depression, and sleep disturbance would be significant predictors of symptom duration***, even considering the above factors. Behavioral disturbances following pediatric mTBI including mood and sleep are well documented in the literature and were reviewed in-depth in Chapter Two. Prior support for psychological factors associated with recovery is described above and outlined in Table 4.

METHODS

Study Design

The present project was part of an ongoing study of individuals with concussion, the North Texas Concussion Registry (ConTex), which was designed to capture comprehensive, longitudinal data on children and adults who have suffered SRC or other forms of mild TBI. Data utilized in this study were collected between September 2015 and April 2018. Participants presented for evaluation following injury to one of the collaborating outpatient clinics including UT Southwestern Medical Center, Children's Medical Center, Texas Scottish Rite Hospital for Children, and Texas Health Resources. Research coordinators screened for eligibility to enroll in the study and obtained informed consent, assent, and HIPAA documents. ConTex study approval was granted separately through the UT Southwestern Medical Center and Texas Health Resources Institutional Review Boards.

The ConTex registry used a standard minimum dataset across participating clinics. Demographic and clinical information were collected through semi-structured interviews as part of standard clinical care. Study personnel collected items at the initial clinic visit where gaps existed in the patient's medical record. For the present study, all assessment utilized athletes' self-report (rather than informant report) due to the discrepancy often observed between parent and adolescent reports of affective symptomatology (Smith, 2007). Participants received $25 remuneration following completion of study measures at initial clinic visit. Three months after enrollment, research coordinators conducted additional medical record reviews to retrospectively retrieve items collected by physicians during follow-up clinical visits.

Participants

The current sample included English-speaking middle and high school (N = 393) students aged 12-18 sustaining SRC. Only athletes who presented for an initial clinic visit within two weeks of injury were included. Restricting the range for time to evaluation allowed for assessment of subacute postconcussive symptoms and control of the possible confound of delayed concussion management on recovery time. Specifically, in adolescent athletes, those presenting later to clinic are at greater risk for prolonged recovery (Asken et al., 2016; Berz, Cheng, & Quintiliani, 2017; Elbin et al., 2016). This effect may be, in part, due to delayed concussion management, though several confounding factors likely impact this result (Nelson et al., 2016; D. J. Thomas et al., 2018).

Measures

Medical and injury information. Basic sociodemographic information included age, sex, racial/ethnic background, years in school, and school type (public, private, or charter). Other baseline information was the number of prior concussions and history of psychiatric illnesses including ADHD, anxiety, and depression. Details of the concussion collected included the date of injury, the sport played while injured, and whether the athlete was immediately removed from play. Loss of consciousness (LOC), post-traumatic amnesia (PTA), and retrograde amnesia (RA) served as injury severity indicators.

Postconcussive symptom scale. The Sports Concussion Assessment Tool–3rd edition (SCAT-3) symptom evaluation is a 22-item inventory of postconcussive symptoms (Guskiewicz et al., 2013). Items included common physical (e.g., dizziness, insomnia), emotional (e.g., irritability, sadness), and cognitive (e.g., confusion, memory problems) concussion sequelae. Each symptom was rated as 0 for not having that symptom, 1-2 for mild, 3-4 for moderate, and 5-6 for severe. Ratings were combined to produce a symptom severity score ranging from 0 to 132, with higher scores indicating increased symptoms. The reliability and validity of the SCAT-3 symptom evaluation has been documented in high school and collegiate athletes (Chin, Nelson, Barr, McCrory, & McCrea, 2016).

Generalized Anxiety Disorder 7-item Scale. The Generalized Anxiety Disorder 7-item Scale (GAD-7) is a practical instrument used to briefly measure or assess one of the most common mental disorders. Though designed for generalized anxiety disorder, it has demonstrated good ability to screen and measure severity of other anxiety disorders including panic disorder, social anxiety disorder, and post-traumatic stress disorder. Items were rated as 0 (not at all), 1 (several days), 2 (more than half of the days), and 3 (nearly every day) for the past two weeks and combined into a total score. The cut off points for mild is a score of 5, for moderate is 10 and for severe anxiety is a score of 15. An additional item asks for a frequency rating of being bothered by endorsed symptoms. The GAD-7 has demonstrated adequate internal consistency and test-retest reliability as well as construct, convergent, and discriminant validity (Kroenke, Spitzer, Williams, & Lowe, 2010). It has demonstrated validity in adolescent populations (Mossman et al., 2017).

Patient Health Questionnaire Depression Scale. The Patient Health Questionnaire 8-item Depression Scale (PHQ-8) is a multipurpose instrument used for diagnosis, screening, monitoring and measuring the severity of depression. The full scale incorporates the nine DSM-IV depression diagnostics criteria. However, the 8-item self-report tool was used because it does not contain an item concerning suicidality (for research purposes). Symptoms frequencies are rated on the same scale as the GAD-7 and combined into a severity index. Total scores of 5, 10, 15, and 20 represent mild, moderate, moderately severe, and severe depression in both the 8- and 9-item versions of the scale (Kroenke et al., 2009). Similar to the GAD-7, the frequency of being bothered by symptoms is rated. This instrument is standardized and validated including for use with adolescents and individuals following TBI (Allgaier, Pietsch, Fruhe, Sigl-Glockner, & Schulte-Korne, 2012; Fann et al., 2005; Kroenke et al., 2010).

Pittsburgh Sleep Quality Index. The Pittsburgh Sleep Quality Index (PSQI) is a self-rated 19-item measure of sleep quality. This is a widely-used scale that assesses subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. Each component was rated from 0 (no difficulty) to 3 (severe difficulty) and combined to create a global score ranging from 0 (no difficulty) to 21 (severe difficulty across areas), with scores greater than 6 indicating poor sleep. It has demonstrated good internal consistency, test-retest reliability, and is sensitive and specific for insomnia (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). It also has support for validity in adolescent and TBI populations (de la Vega et al., 2015; Fictenberg, Putnam, Mann, Zafonte, & Millard, 2001).

Recovery time. As part of standard clinical care, athletes were followed until concussion symptom resolution and their clinicians documented recovery. Defining concussion recovery as reaching a totally asymptomatic state is considered flawed given that postconcussive symptoms are non-specific and frequently occur in healthy adolescents (Alla, Sullivan, & McCrory, 2012). Additionally, Custer et al. (2016) report that for student athletes with high levels of baseline symptoms, their endorsement does not change significantly during the acute period of recovery. For the purpose of this study, recovery was defined as a reduction in symptoms such that the athlete could start gradually resuming athletic activity. All ConTex physicians adhered to international concussion consensus guidelines in determining athletes' readiness to begin a graded, stepwise return to sport (McCrory et al., 2017). The number of days between concussion and return-to-play (RTP) protocol initiation was obtained during three-month medical record review.

Statistical Analyses

Survival analysis was employed such that Kaplan-Meyer failure plots and Cox proportional hazards models estimated the relationship of the nine predictors on recovery time. Rather than modeling survival, per se, in this case the outcome was failure to recover (i.e., symptomatic). Unique to this statistical method is the inclusion of censored participants whose recovery time is unknown either because they were lost to follow-up or had not reached asymptomatic status. Missing data in survival analysis is handled via censoring at the latest time point of known recovery. Participants with incomplete follow up were censored at their first visit, and participants who failed to recover were censored at three-month follow-up.

Predictors included sex (male/female), prior mental illness (yes/no), LOC (yes/no), amnesia (none or PTA/RA), past concussions (none, single, or multiple), postconcussive symptom severity score, GAD-7 total score, PHQ-9 total score, and PSQI global score. Forward entry using the Wald test was selected in order to build the most parsimonious model. Previously established risk factors from personal history (i.e., sex, preinjury psychiatric disorder, and multiple concussions) and concussion severity indicators (i.e., LOC, amnesia, and symptom burden) were entered in the first block in order to detect the most important predictors, with psychological predictors (i.e., anxiety, depression, and sleep quality) in a subsequent block to discern their separate impact on recovery. All statistical assumptions were checked. Statistical significance was set at $\alpha = .05$. Analyses were performed using IBM SPSS for Windows (version 24).

To supplement the above survival analyses, Kruskal-Wallis nonparametric tests examined sex differences on each item of the postconcussive symptom log, GAD-7, and PHQ-8 scales. A conservative Bonferonni correction was applied. In addition, a Poisson regression analysis of days to symptomatic recovery was conducted using the subset of participants (n = 287; 72% of total sample) with a known date of symptom clearance. Unlike survival analysis, this method handles only recovery time as an outcome and, thus, did not include censored cases. The same nine predictors were used and were entered into the model simultaneously. Nonsignificant predictors were removed from the full model to improve overall model fit.

RESULTS

Participants were 216 males and 177 females (79% Caucasian, 18% Hispanic) aged 12-18 years (M = 14.7, SD = 1.6). The most commonly played sport during injury was football (28%), followed by soccer (23%) and basketball (13%). On average, the time from injury to clinic visit was 5.7 days (range: 0–14). Loss of consciousness was experienced in 13% and amnesia (either PTA or RA) in 25% of injuries. There were 110 (28%) participants with a prior history of concussion, 34 of which included multiple injuries. Of the 35 (9%) participants with a history of psychiatric disorder, 33 had anxiety and/or depression. Forty-five (12%) participants had ADHD. Table 5 summarizes demographic and clinical information from initial visit.

By three-month follow-up, 276 athletes (70%) had reached symptom clearance. Date of recovery was unknown for 117 athletes; 77 (20%) had not yet completed a follow-up visit, and 40 (10%) had follow-up but were not yet returned to sport. Approximately half of the 393 athletes in our sample (n = 203, 52%) experienced recovery within 27 days. Figure 1 depicts a histogram of recovery time.

The first block of the Cox regression model contained only amnesia and postconcussive symptoms (maximum p = .013). After psychological factors were added in the second block, amnesia (HR= 0.64, 95% CI = 0.46–0.89, p = .010), postconcussive symptoms (HR = 0.99, 95% CI = 0.98–1.00, p = .002), and PSQI total score (HR = 0.92, 95% CI = 0.86–0.97, p = .002) were selected as predictors. The final model was significant overall, $\chi^2(3)$ = 35.96, p < .001, with a significant change from the first to the second block, $\chi^2(1)$ = 10.08, p = .001. Regression results are summarized in Table 6.

Although sex differences in recovery were anticipated based on prior findings summarized above, sex did not meet entry criteria for the Cox hazards model. Despite not being an additive predictor in the full regression, a log rank test of sex indicated significantly different recovery functions, $\chi^2(1)$ = 5.76, p = .016, with median times of 18 and 23 days for males and females, respectively. When separate Cox regression models were run for males and females, only postconcussive symptoms (HR = 0.98, 95% CI = 0.98–0.99, p < .001) were predictive of recovery for females and PHQ-8 total score (HR = 0.92, 95% CI = 0.87–0.97, p = .003) for males, with each overall model significant (maximum p = .001). A summary of regression results for separate models of males and females are in Table 7. Figures 2–3 contain boxplots for each continuous predictor separated by sex and time symptomatic.

Analysis of male and female reporting on the GAD-7 and PHQ-8 scales revealed no differences on the individual item level. However, there were sex differences on seven items of the symptom log: headache, dizziness, drowsiness, sensitivity to light, sensitivity to noise, pressure in head, and feeling slowed down, with females endorsing higher levels of each symptom than males. Last, a Poisson regression analysis of days to symptomatic recovery was conducted. The subset of participants with a known date of symptom clearance included 276 athletes (70%). Eight of the nine individual predictors reached were significant. History of psychiatric disorder, LOC, and PSQI score were not significant (*p*s > .05) and removed from the final model. The overall model was significant, $\chi^2(7) = 754.16$, $p < .001$. Six of the nine predictors were significant and included in the final model. These were sex, previous concussions, amnesia, postconcussive symptoms, GAD-7 score, and PHQ-9 score (maximum p = .001). The variance inflation factor (VIF), an indicator of a linear relationship one predictor in the model has with another predictor, was acceptable for each predictor in the model (VIF range: 1.01–1.90), with values greater than ten concerning for multicollinearity (Menard, 2002). The results are summarized in Table 8. Holding constant all other measures, the impact of each individual predictor on recovery time was as follows:

- **Sex**: Females' recovery was 20% longer than males.
- **Psychiatric history**: Recovery time did not significantly differ for athletes with and without a prior history of psychiatric disorder.
- **Prior Concussion**: Athletes experiencing their second concussion had 26% longer recovery times than athletes for whom this was their first injury. Recovery for athletes with a history of multiple concussions was 62% longer than athletes without a prior concussion history.
- **LOC**: Athletes with and without LOC had similar recovery times.
- **Amnesia**: Recovery from injuries resulting in PTA or RA was 23% longer.
- **Postconcussive symptoms**: For every 1-point increase on the postconcussive symptom severity score, indicating increased symptom severity, recovery time increased by 1%.

- **Anxiety symptoms**: For every 1-point increase on the GAD-7 total score, indicating increased symptom severity, recovery time increased by 1%.
- **Depression symptoms**: For every 1-point increase on the PHQ-8 total score, indicating increased symptom severity, recovery time increased by 3%.
- **Sleep quality**: Recovery time did not significantly differ with changes on PSQI global score.

DISCUSSION

This is one of the first prospective studies of concussion recovery to examine the relationship between initial postinjury emotional functioning and symptom recovery in adolescent athletes, while controlling for other risk factors for protracted recovery. In our sample, approximately half of athletes (52%) reached symptom recovery by postinjury day 27, as determined by a physician. This finding was mostly consistent with a recent large study (n = 1,840) in which 61% of high school athletes recovered within 0-21 days and 26% recovered 28 days or later (D. J. Thomas et al., 2018). Prolonged postconcussive symptoms (i.e., those lasting longer than 90 days) was observed in 10% of our sample, matching a representative sample of U.S. high school athletes conducted by Chrisman et al. (2013).

We hypothesized the following injury and medical history predictors, despite having been inconsistently linked to recovery in past literature (see Tables 3 and 4), would be predictive of symptom recovery: **(i)** sex, **(ii)** premorbid history of psychiatric illness, **(iii)** prior concussion history, **(iv)** LOC, **(v)** amnesia, and **(vi)** initial postconcussive symptom severity. As predicted, sex, prior concussion, amnesia, and postconcussive symptoms, which were all significant individual predictors of symptom recovery time in the Poisson regression model. Several findings emerged that were in contrast to our predictions. Though a carefully designed study utilizing similar outcomes and analyses supported LOC and longer symptom recovery (Heyer et al., 2016), a comparison of early (3 week) and late (3 month) recovery did not find a relationship between LOC, but identified that a prior psychiatric disorder was predictive (Morgan et al., 2015). However, neither of these findings (LOC or psychiatric disorder) were replicated by a later study examining days to recovery in middle and high school athletes (Terwilliger et al., 2016). In our sample these were fairly low base rate events (13% and 10%, respectively) and not significant risk factors of longer recovery time. In the Cox survival analysis for recovery, presence of amnesia and greater postconcussive symptoms were risk factors for being symptomatic across time points.

In addition, we examined three more psychological predictors for a total of nine: **(vii)** postinjury anxiety symptoms, **(viii)** postinjury depressive symptoms, and **(ix)** postinjury sleep disturbance. Even after controlling for the influence of other known predictors (i–vi), both symptoms of anxiety and depression predicted longer recovery time, as was hypothesized. This was despite a fairly mild degree of symptoms in our sample. In the general population, anxiety and depression are among the most common psychiatric disorders with onset in childhood (Achenbach, Howell, McConaughy, & Stanger, 1995). However, we have strides to make in detecting and treating this population, as fewer than 50% of children meeting criteria for depression will receive treatment before entering adulthood (Kessler, Avenevoli, & Ries Merikangas, 2001). Max, Friedman, et al. (2015) identified poorer adaptive functioning in children who developed a new-onset anxiety disorder after mTBI, and we would expect this to correlate with worse outcomes. Grubenhoff et al. (2016) identified that internalizing problems such as depression and anxiety can exacerbate an adolescent's experience of somatic symptoms, which would in turn delay symptom recovery.

When separate survival analyses were created for each sex, differences in recovery predictors emerged. Of the premorbid predictors, amnesia was the strongest predictor of symptom recovery in males, but the same effect was not observed in females. Instead, there was a strong relationship between increased postconcussive symptoms and symptom recovery. Given previously described sex differences in symptom reporting (Frommer et al., 2011), this may be at the heart of the observed discrepancy. Depressive symptoms were associated with being symptomatic across time points for males, but this effect was not observed for females. Similar to previous reports, postconcussion depression scores did not differ for males and females (Kontos, Covassin, et al., 2012), including on an individual item level. Biases in symptoms reporting, which have been described in high school athletes (Kontos, Elbin, et al., 2012), could be at play. This is similar to the findings in a sample of predominantly male student athletes (n males = 51, 68%), which linked greater depressive symptoms to poorer neurocognitive performance in the acute and subacute period after concussion (Kontos, Covassin, et al., 2012). A recent study of concussed children evaluated within an outpatient clinic (N = 92, 61% male) found that depression was linked to postconcussive symptoms persisting for three or more months following injury (Stazyk, DeMatteo, Moll, & Missiuna, 2017).

The present study found postinjury sleep quality and depressive symptoms were predictors of recovery in adolescents following SRC. Postinjury psychological factors, including anxiety, depression, posttraumatic stress, and emotional distress, have also been found to either prolong symptom recovery or predict the development of postconcussive syndrome in adults with mild TBI in emergency department settings (Dischinger, Ryb, Kufera, & Auman, 2009; Meares et al., 2011; Snell, Surgenor, Hay-Smith, Williman, & Siegert, 2015). While research in children with mTBI is more limited, contributions of postinjury psychological factors, including depression, somatization, and emotional symptoms, to prolonged symptom recovery or the development of postconcussive syndrome in children in emergency department settings have also been documented (Grubenhoff et al., 2016; Grubenhoff, Deakyne, Comstock, Kirkwood, & Bajaj, 2015; Taylor et al., 2010). This pattern can also be found in moderate-to-severe pediatric TBI, as studies have found that pediatric TBI is associated with the risk of developing new internalizing disorders and symptoms, including depression, anxiety, obsessive compulsive disorder, and posttraumatic stress disorder, which complicate recovery and result in poorer functional outcomes (D. R. Bloom et al., 2001; Grados et al., 2008; Luis & Mittenberg, 2002).

The presence of these findings in other brain injury populations could implicate a neurological etiology of symptom recovery. However, these findings are not specific to brain injury alone, but have also been found in both sports-related and not sports-related orthopedic injury populations (e.g., anterior cruciate ligament reconstruction, total joint arthroplasty, lumbar spine surgery). Specifically, poorer injury recovery and surgery outcomes in individuals with orthopedic injuries have also been linked to postinjury psychological factors such as depression, anxiety, low self-efficacy, and emotional stress (Brewer et al., 2000; Lavernia, Alcerro, Brooks, & Rossi, 2012; Skolasky, Riley, Maggard, & Wegener, 2012). Thus, the presence of these findings in similar populations, including mTBI in the general population, moderate-to-severe TBI, and athletes sustaining extracranial injuries, must be considered when drawing conclusions.

Limitations and Future Directions

Study limitations include limited generalizability, potential confounding variables, and sample size. First, our sample consisted of predominantly Caucasian volunteers presenting at four north Texas clinics and may not generalize in more diverse groups such as ethnic or racial minorities with documented differences in SRC recovery (Iverson et al., 2017). Second, confounding factors unrelated to recovery may have potentially influenced the date of physician clearance. Scenarios such as the end of a sport season or restricted availability of practitioners can increase the delay to clinical follow-up after symptom resolution has occurred. Patients' motivation to return to clinic may vary as pressure to return to sport increases due to an upcoming competition date or decreases after the conclusion of the season. Third, a larger sample size is needed to confirm findings before firm conclusions can be drawn.

Future well-controlled studies should further investigate outcomes using larger, more diverse samples. Comparison with a non-mTBI control group would help distinguish which factors were specific to brain injury. Outpatient clinics are not the only source for recruitment of mTBI samples; thus, replication other settings (e.g., emergency department, primary care) may help with generalizability. LOC and psychiatric history may not have been predictive in any of the above analyses due to small cell sizes. As these are relatively low frequency events, future studies could make use of matched controls for comparisons. In addition to adolescents' self-reported symptoms, parent or informant observation could be used to validate these results. With regard to sleep, objective measures such as actigraphy could supplement subjective report. Additional time points for comparisons such as adolescents' baseline levels of functioning or long-term recovery across the developmental age span would also be helpful.

CONCLUSION

In sum, we identified an association with recovery using postinjury psychological screeners. Brief psychological screeners following SRC in adolescents may aid treatment and recovery prediction, though further study is needed. Further exploration of the role of mood and sleep issues in adolescents experiencing protracted postconcussion recovery is needed before firm conclusions can be drawn.

CHAPTER FOUR
General Dissertation Conclusions

Concussion is a serious health problem for youth, and variability in recovery is poorly understood particularly for youth. The consequences of sports-related concussion (SRC) and other mild traumatic brain injuries are well documented for cognitive and physical domains. However, descriptions of psychological and social sequelae are less robust, particularly for young athletes. Several lines of evidence suggest that psychological sequelae of concussion produce disruptions in an adolescent's life. Student athletes experience a unique set of issues following SRC within the context of home, school, sport, and social environments. Furthermore, although symptoms of concussion typically resolve within days or weeks, psychological and social disruption may persist for a subset of individuals.

To aid in understanding these issues, literature examining behavioral, social, and emotional implications of sports concussion in youth were summarized. We organized summaries underneath the headings of emotional/social dysfunction, behavioral problems, academic difficulties, sleep disturbance, headache and pain, and quality of life (QOL). Because this body of literature was small, it was supplemented by studies from the general pediatric mild traumatic brain injury literature. These consolidated findings provide evidence for dysfunction within each psychological/social domain as a result of postconcussive symptomatology, as well as a link between dysfunction and recovery time in this pediatric sport population. Given limitations in the existing literature, future well-controlled research is needed in larger samples.

The knowledge base consolidated in the literature review was sufficient to inform hypothesis for a novel data analysis, which utilized an existing prospective study of concussion recovery to examine psychological factors on recovery. Given that there is minimal support for psychological predictors at this time, a stepped survival analysis was used such that previously described injury and medical risk factors were added first, then psychological factors. A statistical approach aimed at building the most parsimonious recovery model of recovery time was used. Further, separate models for each gender were run in order to identify gender differences in the prognostic indicators of recovery.

When gender was not taken into account, the presence of amnesia, greater postconcussive symptoms, and greater sleep difficulties reduced the likelihood of recovery at any given time point. However, examining recovery separately for each gender revealed unique predictors. The greatest influence for females was increased postconcussive symptoms. For male athletes, increased depressive symptoms had the greatest impact and reduced the likelihood of recovery. These findings provide preliminary evidence for the utility of depression and sleep assessment as part of concussion management in adolescent student athletes, while offering further support for previously established risk factors for prolonged recovery.

For a subset, concussion sequelae persist for weeks to months. Though further replication is needed, this project highlights the potential of postinjury psychological functioning in determining which youth may be at elevated risk for prolonged concussion recovery. Given that screening tools for mood and sleep demonstrated predictive utility for concussion recovery, it is surprising that emotional functioning is such a small portion of the typical postconcussion evaluation. Early management of potentially deleterious social, behavioral, or emotional consequences experienced by athletes following concussion will be important to prevent or mitigate distress.

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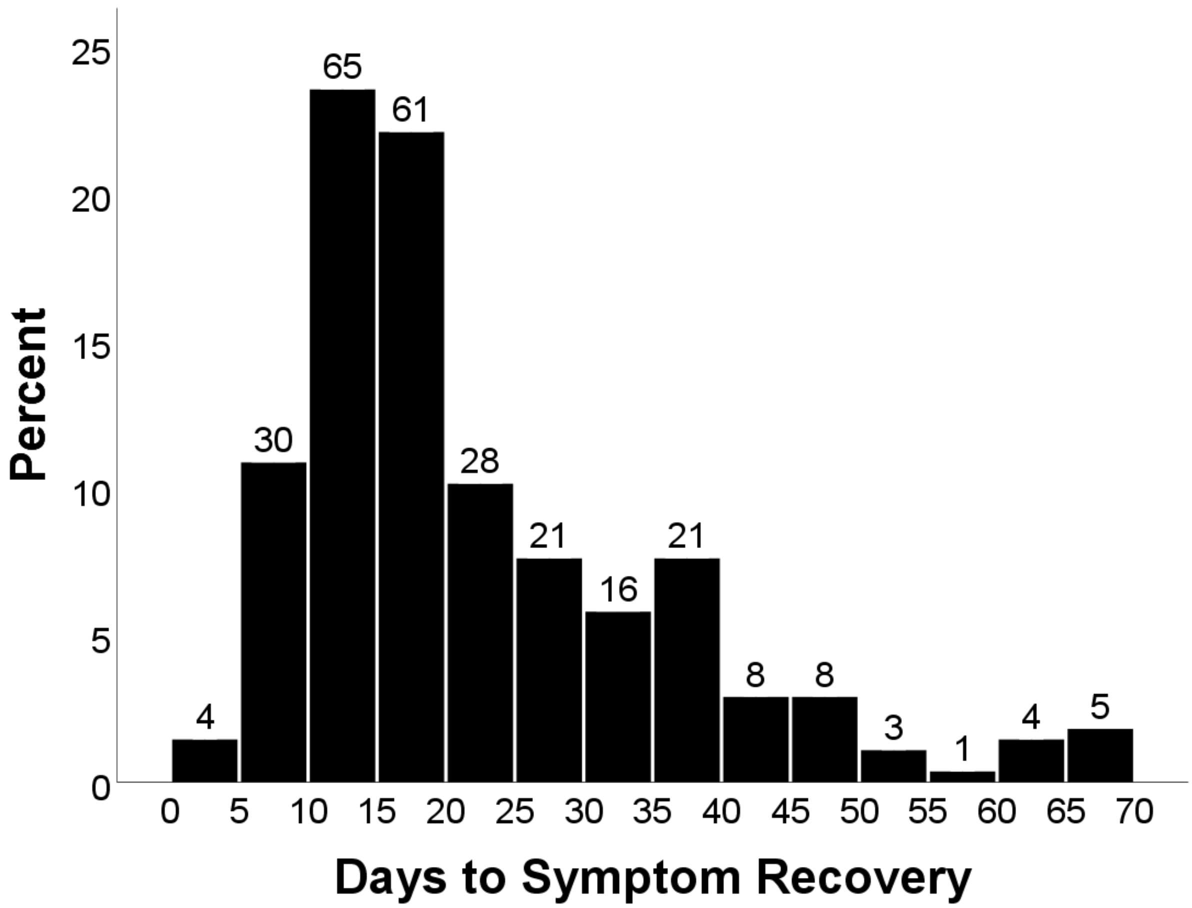

Figure 1. Histogram of time to symptom clearance

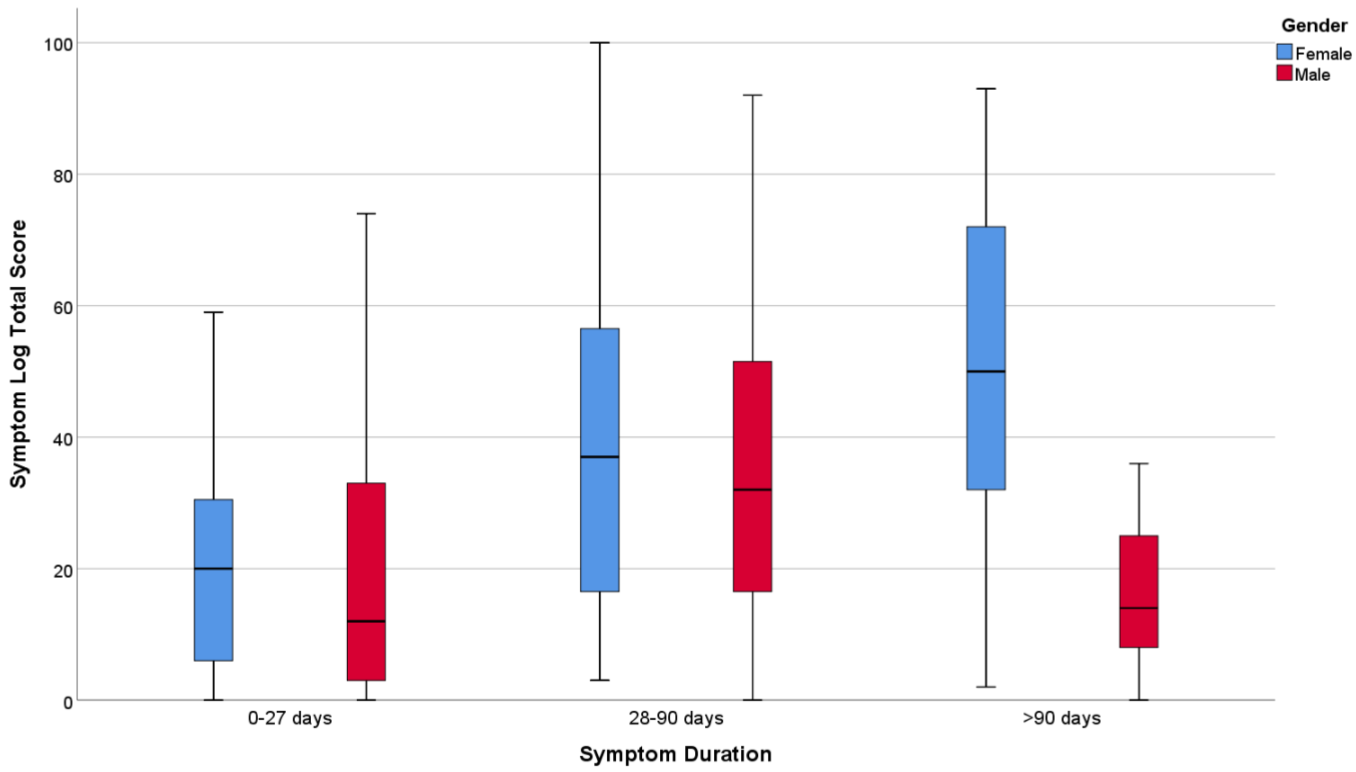

Figure 2. Boxplot for postconcussive symptom severity score

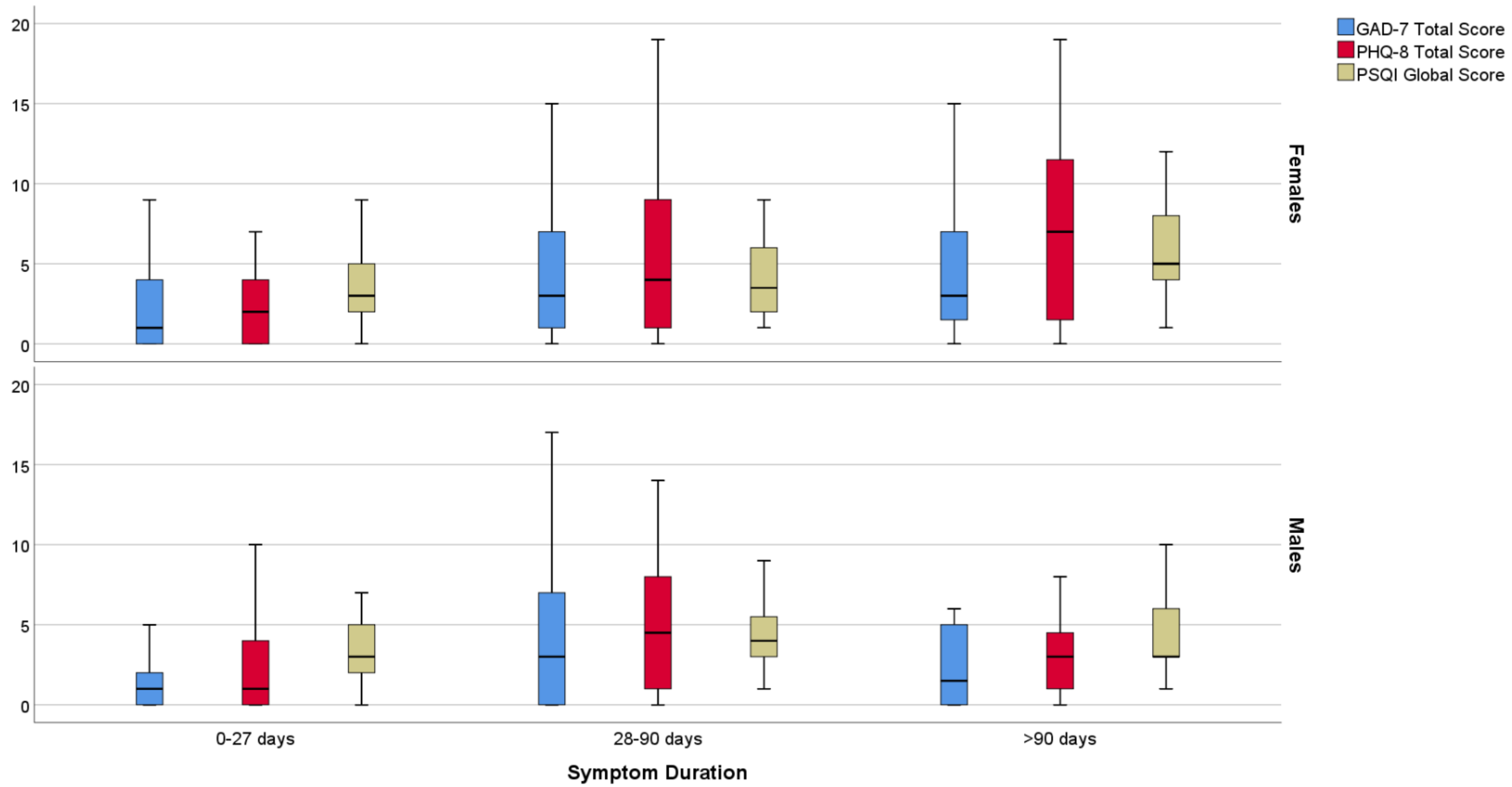

Figure 3. Boxplots for anxiety, depression, and sleep scores

Table 1.

Database Queries Conducted for Literature Review

MEDLINE
1. Brain concussion (MeSH Term) OR concuss* OR mild traumatic brain injur*
2. Psychiatry OR emotional adjustment OR behavioral medicine OR mental disorders OR mental health services (MeSH Terms)
3. Adolescent OR young adult OR child OR minors (MeSH Terms)
4. Student* OR young adult* OR adolescen* OR pediatric OR children* OR youth*
5. 3 OR 4
1 AND 2 AND 5
509 articles returned
PsycINFO
1. Brain concussion (Index Term)
2. Concuss* OR mild traumatic brain injur* OR mild head injur*
1 OR 2
95 articles returned

Note: Asterisks indicate broad word endings were included. Searches included articles published 11/14/2006–5/17/2018.

Table 2.

Overview of Pediatric Studies Examining Psychological and/or Social Sequelae of Sports-Related Concussion

Study	mTBI Sample Size	Ages, y	Sample Characteristics
Baker et al. (2015)	91	13-19	Students evaluated by a physician following a sports-related concussion (SRC) observed by a team athletic trainer (AT).
Collins et al. (2003)	109	15.8 ± 1.2	High school athletes with SRC diagnosed on field by a physician.
Ellis et al. (2015)	174	14.2 ± 2.3	Chart review for patients aged ≤19 who were diagnosed within 30 days of SRC by physicians using consensus statement guidelines.
Frommer et al. (2011)	Year 1: 391 Year 2: 421	$M_{\text{Year 1}}$: 15.9 $M_{\text{Year 2}}$: 15.9	Concussions sustained during practice or competition requiring AT/physician attention resulting in restricted sport participation.
Houston, Bay, & Valovich McLeod (2016)	122	15.8 ± 1.1	High school athletes sustaining a SRC.
Iadevaia, Roiger, & Zwart (2015)	7	12-16	Adolescent student-athletes sustaining a first SRC who were examined by an AT and diagnosed by a physician.
Kostyun, Milewski, & Hafeez (2015)	545	11-18	Patients treated for SRC, identified via chart review.
Lau, Collins, & Lovell (2011)	108	M_{Short}: 16.12 M_{Long}: 15.90	Male high school football athletes divided into early (≤14 days, n=58) and late (>14 days, n=50) symptom clearance groups.
Makki et al. (2016)	42	14-19	Adolescent student-athletes with SRC.
Meehan, d'Hemecourt, & Comstock (2010)	544	13-18	High school athletes sustaining a concussion.

Note: Studies were excluded if samples combined concussed pediatric athletes with other populations (e.g., collegiate athletes).

Table 2, Continued	Setting	Relevant Measures	Psychological/Social Results
Baker et al. (2015)	Outpatient concussion clinic in New York between 2010-2012	Sport Concussion Assessment Tool–2 (SCAT2), computerized neurocognitive testing, and telephone interview	School problems associated with postconcussive symptoms (including irritability and trouble falling asleep) and neurocognitive performance <9th percentile.
Collins et al. (2003)	20 high schools in University of Pittsburgh Medical Center's Sports Concussion Program	Immediate Post-concussion Assessment and Cognitive Test (ImPACT) within 5-7 days	Post-injury headache associated postconcussive symptoms and lower neurocognitive performance.
Ellis et al. (2015)	Outpatient concussion clinic in Winnipeg	Postconcussive symptom log and psychiatric history	Emotional symptoms in 50%. Psychiatric disorder (new or worse) in 10%, of which 25% went untreated.
Frommer et al. (2011)	U.S. High School Reporting Information Online (HS RIO) sport injuries surveillance tool	Postconcussive symptom log	Headache was the most common symptom and most frequently reported as primary. Drowsiness reported by more females than males.
Houston et al. (2016)	15 high schools in Arizona	Pediatric Quality of Life Inventory (PedsQL), Multidimensional Fatigue Scale, and SCAT2 symptom log	Postconcussive symptoms negatively associated with quality of life (QOL). Lower physical QOL, fatigue, and school dysfunction predicted longer return to play.
Iadevaia et al. (2015)	Interscholastic athletes in 2011-2012 from upper Midwest schools	Semi-structured interview	Postconcussive symptoms significantly impacted daily lives, evoked feelings of frustration, and impeded school attendance, activities, and social interactions.
Kostyun et al. (2015)	Sports medicine concussion clinic affiliated with a Connecticut children's hospital	ImPACT within 90 days	Sleeping <7 hours the night prior associated with greater postconcussive symptoms. Sleeping >9 hours associated with lower neurocognitive performance.
Lau et al. (2011)	Pennsylvania interscholastic athletic association football programs in 2002-2006	ImPACT within 2-3 days and postconcussive symptom clusters	Migraine and sleep symptoms more frequent within the long recovery group. Migraine (but not sleep) symptoms were a risk factor for protracted recovery.
Makki et al. (2016)	Outpatient concussion clinic in New York	SCAT2 symptom log and hours in school for 14 days after visit	Postconcussive symptoms associated with number of hours spent in school, controlling for time since injury.
Meehan et al. (2010)	HS RIO	Postconcussive symptom log	Headache was the most common symptom (93%). Drowsiness in 27% and irritability in 9% of injuries.
Russell et al. (2017)	Outpatient concussion clinic in Winnipeg	PCSS, PedsQL, and medical history	Lower physical and cognitive QOL associated with postconcussive symptoms and longer recovery.

Table 3.

Premorbid Factors Related to Longer Concussion Recovery in Middle and High School Athletes

Factor supported	Not supported
Females	
<u>Continuous outcome:</u> Baker et al., 2016 (n = 147); Bock et al., 2015 (n = 361); Kostyun & Hafeez, 2015 (n = 266); Heyer et al., 2016 (n = 1,953); Thomas et al., 2018 (n = 1,840)	<u>Continuous outcome:</u> Baker et al., 2015 (n = 91); Morgan et al., 2015 (n = 120); Ono et al., 2016 (n = 176); Terwilliger, Pratson, Vaughan, & Gioia, 2016 (n = 42) <u>Categorical outcome:</u> Chrisman, Rivara, Schiff, Zhou, & Comstock, 2013 (n = 595); Frommer et al., 2011 (n = 391); Hang, Babcock, Hornung, Ho, & Pomerantz, 2015 (n = 109);
Prior psychiatric disorder	
<u>Categorical outcome:</u> Morgan et al., 2015 (n = 120)	<u>Continuous outcome:</u> Terwilliger, Pratson, Vaughan, & Gioia, 2016 (n = 42)
Prior concussion	
<u>Continuous outcome:</u> Thomas et al., 2018 (n = 1,840) <u>Categorical outcome:</u> Chrisman et al., 2013 (n = 817); Hang et al., 2015 (n = 109); Morgan et al., 2015 (n = 120)	<u>Continuous outcome:</u> Baker et al., 2015 (n = 91); Heyer et al., 2016 (n = 1,953); Terwilliger et al., 2016 (n = 42) <u>Categorical outcome:</u> Barlow et al., 2010 (n = 670); Chrisman et al., 2013 (n = 595); Lau, Collins, & Lovell, 2012 (n = 108); Mautner, Sussman, Axtman, Al-Farsi, & Al-Adawi, 2015 (n = 108)

Table 4.

Postinjury Factors Related to Longer Concussion Recovery in Middle and High School Athletes

Factor supported	Not supported
Loss of consciousness	
Continuous outcome: Heyer et al., 2016 (n = 1,953)	Continuous outcome: Bock et al., 2015 (n = 361); Terwilliger et al., 2016 (n = 42) Categorical outcome: Chrisman et al., 2013 (n = 595); Morgan et al., 2015 (n = 120)
Amnesia	
Continuous outcome: Heyer et al., 2016 (n = 1,953) Categorical outcome: Chrisman et al., 2013 (n = 595)	Continuous outcome: Bock et al., 2015 (n = 361) Categorical outcome: Lau, Kontos, Collins, Mucha, and Lovell, 2011 (n = 107); Terwilliger et al., 2016 (n = 42)
Greater symptoms	
Continuous outcome: Heyer et al., 2016 (n = 1,953); Thomas et al., 2018 (n = 1,840) Categorical outcome: Chrisman et al., 2013 (n = 595); Greenhill et al., 2016 (n = 4,311); Hang et al., 2015 (n = 109); Iverson, 2007 (n = 114)	Categorical outcome: Barlow et al., 2010 (n = 670); Morgan et al., 2015 (n = 120)
"Emotional" symptoms	
Continuous outcome: Heyer et al., 2016 (n = 1,953)	Categorical outcome: Morgan et al., 2015 (n = 120)

Table 5

Sample Characteristics

	Males n = 216	Females n = 177	Total Sample n = 393
Age, mean (SD), y	15.0 (1.6)	14.7 (1.6)	14.7 (1.6)
% White	78.7	79.7	79.1
% Hispanic	18.1	18.6	18.3
Sport			
% Football	50.0	1.1	28.0
% Soccer	13.0	36.7	23.7
% Basketball	9.3	16.9	12.7
% Other	27.8	45.2	35.6
% Prior concussion	28.7	27.1	28.0
% Psychiatric disorder	8.8	10.7	9.7
% ADHD	14.4	7.9	11.5
Days to clinic, mean (SD)	5.8 (3.8)	5.6 (3.8)	5.7 (3.8)
% With loss of consciousness	14.4	11.3	13.0
% With amnesia (PTA/RA)	20.4	31.1	25.2

Note. ADHD=attention-deficit/hyperactivity disorder, PTA=post-traumatic amnesia, RA=retrograde amnesia.

Table 6

Cox proportional hazards model for recovery

Predictor	B	SE	Wald	df	*p*	Hazards Ratio (95% CI)
Block 1: Injury/Medical Predictors of Recovery						
Amnesia (PTA/RA)	-0.43	0.17	6.23	1	.013	0.65 (0.47–0.91)
Symptom log score	-0.01	<0.01	17.02	1	<.001	0.99 (0.98–0.99)
Block 2: Mood/Sleep Predictors of Recovery						
Amnesia (PTA/RA)	-0.44	0.17	6.72	1	.010	0.64 (0.46–0.89)
Symptom log score	-0.01	<0.01	9.31	1	.002	0.99 (0.98–1.00)
PSQI global score	-0.09	0.03	9.50	1	.002	0.92 (0.86–0.97)

Note. Abbreviations: PTA, post-traumatic amnesia; RA, retrograde amnesia; and PSQI, Pittsburgh Sleep Quality Index. Predictors entered in block 1: sex, psychiatric history, concussion history, loss of consciousness, amnesia, and symptom log score. Predictors entered in block 2: Generalized Anxiety Disorder 7-item Scale total score, Patient Health Questionnaire 8-item Depression Scale total score, and PSQI global score. Statistical selection of predictors was employed. The overall model was significant at each step (*p*s < .001).

Table 7

Separate Cox proportional hazards model for each sex

Predictor	B	SE	Wald	df	*p*	Hazards Ratio (95% CI)
Females						
Symptom log score	-0.02	<0.01	15.46	1	<.001	0.98 (0.98–0.99)
Males						
Amnesia (PTA/RA)	-0.62	0.25	6.36	1	.012	0.54 (0.33–0.87)
PHQ-8 total score	-0.12	0.04	8.93	1	.003	0.89 (0.83–0.96)

Note. Abbreviations: PHQ-8, Patient Health Questionnaire 8-item Depression Scale. Predictors were statistically selected and included psychiatric history, concussion history, loss of consciousness, amnesia, and symptom log score, Generalized Anxiety Disorder 7-item Scale total score, total score, and Pittsburgh Sleep Quality Index global score. Each model was significant overall (maximum $p = .001$).

Table 8

Poisson regression model for recovery time

Predictor	B	SE	Wald	df	*p*	Odds Ratio (95% CI)
Females	0.18	0.03	45.37	1	<.001	1.20 (1.14–1.26)
One prior concussion	0.23	0.03	56.30	1	<.001	1.26 (1.19–1.34)
Multiple prior concussions	0.48	0.04	131.84	1	<.001	1.62 (1.49–1.76)
Amnesia (PTA or RA)	0.21	0.03	42.87	1	<.001	1.23 (1.16–1.31)
Symptom log score	0.01	<0.01	70.75	1	<.001	1.01 (1.00–1.01)
GAD-7 total score	0.01	<0.01	10.90	1	.001	1.01 (1.01–1.02)
PHQ-8 total score	0.03	<0.01	48.04	1	<.001	1.03 (1.02–1.04)
Constant	2.84	0.03	--	--	--	--

Note. Abbreviations: PTA, post-traumatic amnesia; RA, retrograde amnesia; GAD-7, Generalized Anxiety Disorder 7-item Scale; and PHQ-8, Patient Health Questionnaire 8-item Depression Scale. Predictors were entered simultaneously with recovery time as the outcome variable. The overall model was significant ($p < .001$).