An Exploration of Atypical Recovery from Pediatric Mild Traumatic Brain Injury (mTBI)

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AN EXPLORATION OF ATYPICAL RECOVERY FROM PEDIATRIC MILD TRAUMATIC BRAIN INJURY (MTBI)

by

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ABSTRACT
AN EXPLORATION OF ATYPICAL RECOVERY FROM PEDIATRIC MILD TRAUMATIC BRAIN INJURY (MBTI)

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Mild traumatic brain injury (mTBI) is a significant public health concern, particularly for children and adolescents. Existing research suggests that pre-injury and injury-related factors influence recovery. The current study simultaneously considered variables relevant to recovery from pediatric mTBI, including pre-injury diagnoses, symptom burden, neuropsychological and emotional functioning, performance validity, and medical service utilization in an archival sample of children referred to a multidisciplinary concussion clinic. Consistent with a broad literature, female sex and initial symptom burden predicted referral for neuropsychological evaluation. Initial symptom burden also predicted neuropsychological performance and service utilization. A meaningful proportion of the sample reported clinically significant symptoms of anxiety and/or depression, which negatively influenced neuropsychological functioning. After excluding patients with suspect performance validity, the rate at which individuals obtained impaired neuropsychological scores status-post injury decreased. Finally, this research documented rates of medical service utilization in a sample of children experiencing prolonged recovery from concussion. On average, participants in this sample completed approximately 9 medical visits related to their injury, and initial symptom burden predicted increased service utilization. The current study provides further evidence for the biopsychosocial model of recovery from mTBI and underscores the importance of considering symptom reporting and emotional functioning, as well as routinely assessing performance validity in pediatric mTBI sample.

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Introduction

Mild traumatic brain injury (mTBI) is a significant public health concern for children and adolescents. Broadly, traumatic brain injury (TBI) is defined as the result of head injury due to impact, acceleration, or deceleration (Lezak et al., 2012). *The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (*DSM-5*; American Psychiatric Association [APA], 2013) classifies TBI by the following set of symptoms: loss of consciousness (LOC), occurrence of post-traumatic amnesia (PTA), and/or the presence of neurological indicators including positive neuroimaging, the onset of new or worsening seizures, visual field deficits, olfaction impairment, or hemiparesis. TBIs encompass a broad range of injuries, but most of these injuries (i.e., >70%) are classified as "mild" (Cassidy et al., 2004; Faul et al., 2010).

While the prevalence of mTBI in children is relatively high, research is complicated by the lack of a unifying definition (American Congress of Rehabilitation Medicine, 1993[1]; Carroll et al., 2004a; Culotta et al., 1996). A further issue complicating nosology is a distinction between "uncomplicated" and "complicated" mTBI. It is generally accepted that a key feature defining complicated mTBI is a positive neuroimaging finding (e.g., skull fracture, cerebral edema, contusion, or hematoma; Iverson & Lange, 2011). The classification of complicated injuries as "mild" is debated, as acute presentation is often more symptomatic and recovery trajectories more closely resemble those of moderate TBIs (Iverson, 2006; Williams et al., 1990).

[1] The most frequently cited and commonly applied diagnostic criteria defines mTBI as a head injury resulting in one or more of the following symptoms: LOC for less than 30 minutes, PTA for less than 24 hours, disruption in mental status (e.g., feeling dazed or disoriented), or neurological deficits (e.g., olfactory impairment), and an initial Glasgow Coma Scale score of 13-15.

Heterogeneity in classifying mTBI makes it challenging to determine precise incidence and prevalence rates. Cassidy and colleagues (2004) conducted a comprehensive literature review of mTBI incidence and risk factor studies and observed significant differences across findings related to how mTBI was defined (e.g., inclusion of "complicated" mTBIs or requiring the presence of LOC). Determining accurate prevalence and estimate rates is also challenging because many cases of mTBI are unreported (McCrea, 2008). For example, Sosin and colleagues (1996) estimated that at least 25% of individuals who sustain a mTBI do not seek medical care. Given these uncertainties and discrepancies, the Centers for Disease Control and Prevention (CDC) characterized mTBI as a "silent epidemic" (National Center for Injury Prevention and Control, 2003), and the overall prevalence rate of mTBIs is estimated between 1.4 and 3 million cases per year (Summers et al., 2009). Incidence rates of mTBI have been estimated between 100-300/100,000, although studies that included self-reported injury have estimated incidence rates topping 600/100,000 (Cassidy et al., 2004).

Epidemiological studies have documented that children under 15 sustain mTBI at a higher rate than adults; incidence rates for this age group are estimated at 692/100,000 (Guerrero et al., 2000). In 2009, nearly 250,000 children presented to the ED for treatment of sports- and recreation-related mTBI, which was an increase of 60% compared to 2001 (Gilchrist et al., 2011). Given increased public interest and awareness of mTBI, it is anticipated that these numbers will continue increasing. One significant factor that contributes to the higher incidence rate of mTBI in children is participation in sports. Sport-related concussions[2] (SRCs) make up the majority of mTBIs for children

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[2] Although there is some debate about nomenclature in the literature (Rabinowitz et al., 2014), given the relatively high proportion of injuries that are due to sports-related etiologies, the terms "mTBI" and "concussion" will be used interchangeably (e.g., see Guskiewicz et al., 2007).

under the age of 18 (Langlois et al., 2006). In a cross-sectional study of hospital visits for mTBI in children, the largest percentage of injuries were sport-related (30%) followed by motor vehicle accidents (MVA 20%; Meehan & Manix, 2010). Overall, of the 44 million American children who participate in youth sports, between 1.1 and 1.9 million sustain SRC annually (Bryan et al., 2016). This number is especially alarming given that approximately half of all SRCs go unreported (McCrea et al., 2004).

Clinical Presentation of mTBI

It is well-established that mTBI is associated with a constellation of somatic, emotional, and cognitive symptoms (APA, 2013; Janusz et al., 2012). Physically, individuals who sustain concussion may experience headache, dizziness, fatigue, difficulty sleeping, nausea and/or vomiting, balance deficits, tinnitus, visual deficits or photosensitivity, or other neurological symptoms (McCarthy & Kosofsky, 2015). Emotional symptoms may include irritability, disinhibition, emotional lability, depression, and anxiety. Cognitively, individuals who sustain mTBI often report inattention, confusion, slowed processing speed, and/or memory deficits.

Although the symptom profile associated with mTBI was largely established based on adults' experiences, recent research has suggested that children who sustain mTBI report a similar sequela of general symptoms in the acute phase (Janusz et al., 2012; McCarthy & Kosofsky, 2015; McCrory et al., 2004). In a prospective sample of children presenting at the ED for mTBI, initial symptoms endorsed at the highest frequency included headache (71%), fatigue (67%), difficulty remembering (67%), feeling slowed down (67%), balance problems (60%), dizziness (60%), and drowsiness (60%; Blinman et al., 2009). These findings are consistent with review papers, which have suggested that headaches are the most common post-concussive symptom reported by children and adolescents (e.g., see McCarthy & Kosofsky, 2015). Similar to adult studies, it has also been observed that children who sustain more severe mTBIs (e.g., experience LOC and/or PTA, sustain comorbid orthopedic injuries, or MVAs) endorse more post-concussive symptoms (Taylor et al., 2010).

Although research has indicated that children experience similar symptoms in the acute stage of mTBI recovery, it is important to note that their neuropathology and recovery does not replicate that of adults. Due to the complexities of physical and neurological development, children are not simply “little adults” (Kirkwood et al., 2006, p. 1360) with respect to recovering from mTBIs. Children and adults vary in the threshold of biomechanical forces required to cause mTBI due to developmental factors (e.g., size and shape of the skull relative to internal brain structures, neck musculature, and physiological response to impact; Ommaya et al., 2002). While it is long established that children are at risk for experiencing greater cerebral swelling after sustaining moderate and severe TBI (Aldrich et al., 1992; Sharples et al., 1995), recent research has suggested that this vulnerability extends to milder injuries as well (McCrory et al., 2012). Level of cognitive development should also be considered in children who sustain mTBI. Historically, the potential for neuroplasticity has been considered a protective factor for young children who experience brain injury; however, research suggests that a diffuse injury may disproportionately negatively affect immature brains (Kolb & Gibb, 2007). Some authors have even suggested that sustaining mTBI at a young age, prior to the development of certain cognitive skills, may negatively impact the development of complex cognitive skills later in life (Bodin & Shay, 2012).

Typical Recovery from mTBI

Clinicians' understanding of mTBI recovery has largely emerged from the SRC literature. Identifying the advantages of studying young, healthy athletes, early SRC researchers collected baseline data and prospectively tracked athletes' recovery from concussion (e.g., see Barth et al., 2001; McCrea et al., 2015). These early studies quantified neuropsychological abilities, balance and postural stability, and symptom reporting in the acute stage of recovery (McCrea et al., 2015). The primary methodological advantages of this research include investigating injuries that are observed in athletes who are not engaged in litigation and have a high motivation to recover. To this effect, SRC research reduces some of the confounds associated with other mechanisms of injury (e.g., MVAs or falls; McCrea, 2008).

A robust body of literature suggests that athletes tend to recover quickly and completely from SRC (McCrea, 2008). For example, in a prospective injury study of over 1,500 amateur football players, McCrea and colleagues (2003) observed that most athletes who sustained concussion experienced transient neuropsychological and balance deficits several days status post-injury. Subtle decrements in performance on tasks measuring processing speed, learning, memory, and executive functioning were observed. For 90% of injured athletes, post-injury scores returned to a pre-injury baseline level within one week. The entire sample reached full recovery within 90 days. A meta-analysis of 21 prospective studies of SRC revealed a similar recovery pattern. Most athletes experienced mild-to-moderate neuropsychological impairments in the acute stage of concussion recovery, but the vast majority recovered fully within seven to 10 days (Belanger & Vanderploeg, 2005).

Although prospective research conducted with athletes has consistently indicated that impairments associated with concussion are transient and relatively short-lived, injuries with non-sport etiologies have elicited a different recovery trajectory. In a critical review of mTBI meta-analyses, it was noted that analyses of mixed-mTBI etiology have consistently yielded longer recovery periods (Karr et al., 2014). Meta-analyses of mixed- or non-sport etiologies have observed acute injury effects that dissipate within 90 days (Belanger & Vanderploeg, 2005; Frenchem et al., 2005; Rohling et al., 2011). In a systematic review of 299 studies in which recovery was self-reported by participants, Cassidy and colleagues (2014) observed that although there was significant variance across studies, the vast majority of individuals reported complete recovery within three to 12 months status-post injury.

It is important to recognize that differences in recovery time are often attributed to factors inherent to accidental injury mechanisms (i.e., orthopedic injury, trauma exposure, or litigation involvement) that may interfere with the recovery process. In attempting to further understand these differences, the WHO Collaborating Task Force on mTBI put forth guidelines for mTBI research (Carroll et al., 2004a). In this critical review, Carroll and colleagues pointed out that although many outcome studies have been conducted on recovery from mTBI, few have accounted for confounding injury factors such as trauma exposure, pre-injury diagnoses, orthopedic injury, and use of pain medications. Importantly, these factors likely account for some of the variability in recovery trajectories observed across studies.

Although research has suggested that SRC studies may not accurately predict concussion recovery in the general population, it is methodologically challenging to conduct ecologically- valid research in this realm. As previously discussed, there is significant heterogeneity in the definition and scope of mTBIs included in studies. Additionally, it is nearly impossible to control for the biomechanics of injury. Further, in ED samples, it is difficult to control for many of the confounding issues identified by the WHO Collaborating Task Force. For example, multiple studies have documented attempts to remove or control for confounding variables in emergency department (ED) samples result in excluding nearly all referred patients for mTBI (Furger et al., 2016; Luoto et al., 2013).

Relative to adult mTBI research, fewer methodologically rigorous studies have been conducted to understand children's recovery from concussion. An early literature review suggested that while outcomes vary across studies, those that were more methodologically rigorous (e.g., prospective studies, large sample sizes, and/or the use of controls groups) did not suggest that mTBIs were related to worse long-term outcomes in cognitive, academic, or psychosocial domains (Satz et al., 1997). Carroll and colleagues (2004b) found that most children recover from concussion within two to three months status post-injury. The same study observed that the experience of prolonged symptoms of concussion in children was likely related to premorbid diagnoses or circumstances surrounding the injury (i.e., trauma exposure or other orthopedic injury). Additional prospective studies of children presenting to the ED for mTBI have suggested that the median recovery time for children is about 30 days, and that just over 10% remain symptomatic at three-month follow-up (Barlow et al., 2010; Barlow et al., 2015).

Studies investigating recovery from mTBI relative to multiple control groups have also helped elucidate factors that are related to recovery. Babikian and colleagues (2011) tracked recovery of children and adolescents who sustained mTBI relative to two control groups: children who sustained an orthopedic injury and non-injured controls. At 12-

month follow-up, researchers observed that the non-injured control group performed significantly better than both injury groups on measures of memory, processing speed, and language. Due to the similarities in neuropsychological performances between the orthopedic and mTBI groups, researchers attributed the discrepancy in scores to a general injury effect associated with psychosocial stressors such as missing school or challenges with coping. Importantly, group differences in neurocognitive performances reflected small effect sizes. The authors speculated that differences observed were due to the small portion of both injury groups that experienced atypical neurocognitive recovery. It was posited that most children recover in a timely and complete manner from mTBI, and that cognitive symptoms of concussion are not necessarily due to the injury mechanisms of concussion.

Atypical Recovery and Post-Concussion Syndrome

Across a large body of research documenting mTBI recovery rates, many studies have identified that a “miserable minority” of about 10% of individuals experience prolonged recovery from mTBI (Ruff et al., 1996; Ruff, 2005). These individuals are thought to experience atypical recovery or post-concussive syndrome. Post-concussive syndrome typically refers to the experience of nonspecific cognitive (e.g., forgetfulness or poor concentration), somatic (e.g., headaches, nausea, or noise sensitivity), and emotional (e.g., irritability and emotional lability) symptoms beyond the typical recovery window (Janusz et al., 2012; McCrea, 2008). Post-concussive symptom burden is typically associated with significant functional impairment and poor quality of life (Emanuelson et al., 2003).

A significant challenge to understanding post-concussive syndrome is that associated symptoms are not specific to mTBI. For example, Iverson and Lange (2003) observed that adults with no history of concussion or other diagnoses endorse post-concussive symptoms at rates ranging from 37% to 81%. While individuals with a history of mTBI often report more post-concussive symptoms than healthy individuals, studies have not observed statistically significant differences between groups on self-reported post-concussive symptom burden (Garden et al., 2010). Instead, researchers have observed a relationship between post-concussive symptoms and factors unrelated to injury, including mood symptoms and duration of recovery (Emanuelson et al., 2003; Garden et al., 2010). Because the adult literature has highlighted some of the challenges in defining and understanding post-concussive syndrome, it continues to be a controversial and contested diagnosis.

Similar to the adult literature, pediatric research has sought to examine the rate at which healthy children endorse post-concussive symptoms. In a large-scale study of high school athletes, Iverson and colleagues (2015) observed that a significant portion of participants endorsed a clinically significant level of post-concussive symptoms (19% of boys and 28% of girls). The authors also observed that uninjured athletes with preexisting conditions (e.g., history of migraines, ADHD, or psychiatric treatment) were more likely to endorse post-concussive symptoms. Interestingly, the weakest independent predictor of post-concussive symptom burden in this study was a history of sustaining mTBI. These findings are significant, as they suggest that children experience post-concussive symptoms in the absence of an injury. As such, post-injury symptom reporting may be a misleading metric of recovery.

In contrast to Iverson and colleagues' (2015) findings and much of the adult literature, other researchers have argued that there is sufficient evidence that post-concussive syndrome is a coherent syndrome in children. For example, many studies have observed that injury characteristics are related to the experience of post-concussive symptoms. Taylor and colleagues (2010) found that, compared to an orthopedic injury (OI) control group, children who sustained mTBI reported significantly more post-concussive symptoms. Further, symptom endorsement was related to injury characteristics (i.e., MVA etiology, positive neuroimaging, LOC, and/or longer hospital duration). Similarly, Babcock and colleagues (2013) observed that injury-related factors, including acute symptom burden and hospital admission, were related to greater risk for elevated post-concussive symptoms after three months.

Despite the challenges of assessing post-concussive symptoms, many researchers have attempted to identify the factors and mechanisms that predict which individuals are more likely to experience protracted recovery from concussion. One proposed explanation is preinjury characteristics. Research within the adult realm has primarily focused on premorbid psychological factors and personality dimensions. For example, higher levels of preinjury trait alexithymia and anxiety sensitivity are related to greater endorsement of post-concussive symptoms and longer recovery trajectories (Wood et al., 2014). Similarly, other research has demonstrated that these personality traits are related to both acute and chronic experiences of pain following OI (Wood, et al., 2011). Other studies have suggested that specific personality traits are related to endorsement of post-concussive symptoms in the absence of injury. For example, Garden and colleagues (2010) observed that healthy participants (i.e., those who did not sustain concussion) who endorsed clinically-significant levels of post-concussive symptoms had greater elevations on the Millon Clinical Multiaxial Inventory III (MCMI-III; Millon, et al., 2009) Depression, Dysthymia, Anxiety, Somatic, and Borderline scales compared to those who did not endorse clinically-significant post-concussive symptoms. Pre-injury depressed mood and low levels of resilience also predicted post-concussive symptom burden in a prospective study of recovery from concussion (McCauley et al., 2013).

Collectively, these studies suggest that pre-injury levels of pathological traits and symptoms are related to endorsing post-concussive symptoms. This research is intuitive. Those who experience mood symptoms prior to concussion may be more likely to experience nonspecific affective, somatic, and cognitive symptoms, regardless of injury; however, the nonspecific nature of these symptoms contributes to methodological difficulties studying post-concussive symptoms. To address these limitations, Nelson and colleagues (2016) utilized a prospective study of healthy high school and collegiate athletes to examine the pre-injury factors that predicted duration of recovery from concussion. Researchers included a variety of predictors in the model, including demographic characteristics, psychosocial functioning variables, neuropsychological performance, acute injury variables, symptom report, and vestibular functioning. They observed that premorbid somatization score and symptom report in the acute stage of concussion best predicted duration of recovery. Further, researchers noted that baseline somatization scores influenced acute symptom reporting. By utilizing a sample with a relatively low rate of premorbid psychopathology, this study suggested that the propensity for pre-injury somatic complaints influences both acute and long-term recovery from concussion and suggests that somatization influences recovery above and beyond other relevant factors.

The role of pre-injury somatization in mTBI recovery has also been explored in pediatric samples. Root and colleagues (2016) observed that higher pre-injury somatization ratings were related to prolonged post-concussive symptom burden in children aged 10-18. Specifically, girls in the highest quartile in ratings of pre-injury somatization were at higher risk for endorsing clinical levels of post-concussive symptoms at follow up. Another study considered parent-rated somatization and other pre-injury personality traits (i.e., maladjustment and state and trait anxiety) in delayed symptom recovery. Researchers observed that higher pre-injury somatization ratings were associated with delayed symptom recovery (Grubenhoff et al., 2016).

More recent research has examined samples consisting entirely of children who experience prolonged recovery from concussion. For example, Peterson and colleagues (2015) examined children who experienced post-concussive symptoms between 4- and 26-weeks status post-injury. Children endorsed pre-injury anxiety symptoms at a higher rate than the general population, and a significant relationship between a history of sustaining mTBIs and exhibiting externalizing behaviors was observed. Another recent study considered factors that predicted extended recovery of children referred to a pediatric concussion clinic (Fehr et al., 2017). Uniquely, children presented to the clinic approximately three weeks post-injury, and researchers observed that acute symptom rating predicted atypical recovery. Additionally, female patients were at a higher risk of experiencing a delayed recovery compared to male patients. While these studies shed light on which children might experience prolonged recovery from mTBI, future studies should prospectively examine these factors and others.

While many pediatric post-concussive symptom studies have considered individual factors—either injury characteristics or preinjury factors—that may contribute to complicated recovery from concussion, few studies have simultaneously considered an interaction among these dimensions. For example, Bernard and colleagues (2016) observed that injury factors (e.g., acute symptom burden and LOC) were predictive of post-concussive symptom ratings for up to one-month status post-injury. The experience of post-concussive symptoms beyond one month was more strongly predicted by non-injury factors, including pre-injury learning disabilities, older age at injury, and higher parental stress. Another study identified that cognitive reserve moderated the relationship between injury characteristics and post-concussive symptom ratings (Fay et al., 2010). Specifically, researchers observed that children with lower intellectual ability who sustained a complicated mTBI were more likely to report higher levels of post-concussive symptoms.

A final issue to potentially consider in understanding post-concussive symptoms is performance and symptom validity. Rates of noncredible performance on performance validity tests (PVTs) has been estimated to be as high as 40% when adults who sustain mTBI are involved in personal injury cases (Mittenberg et al., 2002). Many studies have identified that participants who demonstrate suspect effort and task engagement in neuropsychological assessments report greater post-concussive symptom burden than those who put forth adequate performance validity (Broshek et al., 2015; Lange et al., 2010; Lange et al., 2012). Although litigation involvement is relatively rare for children, the role of performance validity is an increasingly important consideration in pediatric neuropsychological evaluations. Studies that have examined the base rates of PVT failure in children vary from 3% to 20% (Green et al., 2011; Kirkwood & Kirk, 2010; Kirkwood et al., 2012; MacAllister et al., 2009). Performance validity is an especially significant concern for children presenting in the context of protracted recovery from concussion. In this population, rates of noncredible performance vary from 12 to 20% across studies (Kirkwood, 2015). While few studies have considered how performance validity impacts post-concussive symptom presentation, Kirkwood and colleagues (2014) and Araujo and colleagues (2014) observed that children who demonstrated noncredible performance endorsed significantly more post-concussive symptoms than those who put forth credible performance. Taken as a whole, emerging pediatric performance validity research suggests that noncredible neuropsychological performance is related to increased symptom reporting.

Atypical Recovery and Service Utilization

Limited research has been conducted to document service utilization or costs of medical care related to childhood mTBI. In general, the number of children and adolescents who receive follow-up care for pediatric mTBI has increased significantly during the past 20 years (Fridman et al., 2018; Macpherson et al., 2014), which reflects efforts to improve awareness and management of these injuries. Population-based research conducted in the United States indicated that states with legislation mandating standard concussion management protocols experienced a two-fold increase in concussion-related ED visits (Mackenzie et al., 2015).

Even less is known about the rate of outpatient service utilization following mTBI. Jimenez and colleagues (2017) conducted a large-scale study of health service utilization after mTBI. Researchers observed that after sustaining mTBI, medical and mental health service utilization increased compared to pre-injury baseline. Children without premorbid psychiatric diagnoses obtained mental health services at a higher rate post-injury compared to pre-injury; however, the majority (i.e., 86%) of mental health visits after injury were sought by children who had pre-existing psychiatric diagnoses. Researchers observed, that for the whole sample, total service utilization peaked in the month after injury compared to baseline or 12 months after injury. After controlling for age and sex, participants completed an average of approximately 4 to 5 medical and/or mental health visits in the month following injury. Additionally, children who had premorbid psychiatric diagnoses demonstrated a significant increase in medical and mental health service utilization beginning one-month status post-injury and peaking 12 months status post-injury. These findings demonstrate that pre-injury psychiatric factors resulted in increased service utilization status-post injury. Of note, although researchers broadly designated visit type (e.g., mental health vs. primary care vs. rehabilitation), it is unclear whether visits were directly related to mTBI.

Summary and Primary Aims

In sum, much of the pediatric post-concussive symptom literature has sought to elucidate whether atypical recovery from mTBI is best attributed to psychogenic factors (e.g., premorbid psychosocial factors) or physiogenic factors (e.g. injury-related factors; Peterson et al., 2015). This debate is underscored by research suggesting that injury factors predict symptom duration (e.g., Babcock et al., 2013; Faris et al., 2016), whereas other studies have suggested that psychosocial functioning variables are more related to the experience of post-concussive symptoms (e.g., Grubenhoff et al., 2016; Peterson et al., 2015; Root et al., 2016).

Studies that have simultaneously considered several variables have observed an interaction between both injury characteristics and psychosocial functioning variables (e.g. Bernard et al., 2016; Fay et al., 2010). Relationships among variables are further obscured by some of the methodological issues present in post-concussive symptom studies. For example, as described above, task engagement and performance validity are important considerations in understanding cognitive recovery. Although studies have estimated that as many as 20% of children demonstrate noncredible performance on cognitive testing (Kirkwood, 2015), many post-concussive symptom studies do not assess symptom and performance validity. In addition, much of the existing research on atypical recovery consists of data collected up to four weeks status-post injury. While this provides important information during the typical window of recovery, it does not capture or describe individuals who may report impairment for months to years after a mTBI. Finally, although research has highlighted some of the functional consequences of prolonged recovery from concussion, little is known about the impact on service utilization or medical costs.

Although it is tempting to distill the cause of atypical recovery into biological and psychosocial factors, recovery from mTBI is likely best explained by a biopsychosocial model (Conder & Conder, 2015; McCrea et al., 2009; Silverberg & Iverson, 2011). While recovery from mTBI is initially due to a biological response to injury, psychological factors, coping skills, and the environmental system likely interact to influence outcomes (McNally et al., 2017). This complex interplay is especially pertinent in children, for whom developmental factors and the family system are particularly relevant influences. Prospective and longitudinal studies that consider a variety of these factors are needed to better understand which children may be at an elevated risk for experiencing atypical recovery and identify targeted interventions.

Given these observations, there is a need for research on pediatric recovery from mTBI utilizing more complex methodologies, including prospective and longitudinal designs, to track recovery from mTBI. Research should also comprehensively consider variables relevant to recovery including psychosocial functioning, medical/psychological interventions, and performance and symptom validity. Further, because atypical recovery from mTBI is associated with a debilitating symptom sequela (Moran et al., 2011; Pieper & Garavan, 2015; Simpson et al., 2017), there is a need for research that considers the clinical features of atypical recovery in children. Although much previous research has examined children in the acute phase up to three months status-post injury, relatively few studies have systematically examined the clinical presentation of children who are slow-to-recover. While children who experience post-concussive symptoms outside of the typical recovery window reflect a relatively small portion of the population, they experience significant subjective distress and functional impairment (Simpson et al., 2017). As such, the proposed project seeks to elucidate risk factors for atypical recovery and to document associated impairments, which will ultimately help inform evidence-based assessment and interventions.

This project will significantly add to an emerging pediatric literature by critically examining factors related to recovery in a sample of pediatric patients who presented in a pediatric multidisciplinary concussion clinic. Broadly, this research will systematically consider neuropsychological and psychosocial factors that are associated with mTBI recovery and healthcare utilization. Uniquely, patients will be tracked longitudinally through medical record review (see Figure 1). The proposed aims for this project are as follows: (1) to describe a sample of patients presenting to a multidisciplinary concussion clinic and identify factors that predict which pediatric patients are referred for a neuropsychological evaluation status-post concussion, (2) to document neuropsychological and emotional functioning, symptom report, and self-reported recovery in a sample of children referred for neuropsychological follow-up, and (3) to utilize neuropsychological evaluation data to predict who is referred for continued treatment in a multidisciplinary concussion clinic. Collectively, these broad aims and associated supplemental analyses will elucidate factors that influence recovery and medical care following mTBI. Ultimately, this research will allow clinicians to more accurately predict recovery and offer targeted interventions.

Methods

Procedure

An archival sample of data collected through the Children's Hospital of Wisconsin (CHW) Concussion Clinic was utilized. CHW Institutional Review Board approval was obtained prior to data extraction. Based on the CHW Concussion Clinic triage process, patients' first contact with the Clinic is generally a referral for evaluation by a sports medicine physician. If symptoms continue to persist beyond expectation or if other early concerns arise about their recovery, patients are referred for a combined neuropsychology/sports medicine visit. After this visit, they may be referred for follow-up visits with neuropsychology, sports medicine, physical therapy, or pediatric psychology.

Relevant cases were identified by conducting two separate medical record searches using a medical records discovery tool query. Medical record queries generated a total of 763 relevant records. Records were divided by group (Group 1 = Sports medicine *only*; Group 2 = Sports medicine *and* neuropsychology), and a random subset of each group was identified using a random number generator. In total, 317 records were screened for eligibility. First, pediatric patients with a formal diagnosis of mTBI or concussion (i.e., with a corresponding ICD code for either diagnosis) who presented in the CHW Concussion Clinic for an initial visit with sports medicine followed by a combined visit with sports medicine and neuropsychology in the past five years were identified (i.e., Group 2).[3] Given previous published research on patients presenting in

[3] Patients were included if they completed their first appointment six months prior to data extraction to ensure adequate time to track medical follow-up, if necessary.

this clinic (e.g., see Fehr et al., 2017), children aged 8 to 18 years were targeted. Participants were included if they sustained a mTBI and completed symptom reporting and self-reported recovery at each visit (i.e., during both their initial visit with sports medicine and their combined visit with neuropsychology). A sample of 100 was targeted, but ultimately, 74 cases were retained for analyses based on inclusion and exclusion criteria. For this group, neuropsychological test data, symptom endorsement, and healthcare utilization were extracted. This group was compared to a sample of 100 pediatric patients who presented at the CHW Concussion Clinic for an initial visit with a sports medicine physician but were not referred for a follow-up combined visit with neuropsychology (i.e., Group 1). Symptom reporting was extracted and required to address Aim 1. One Group 1 participant was excluded from analyses because they ultimately completed neuropsychological testing through another practice, and records were not available, so the total sample size was $n = 99$. After participants were screened, relevant data were transferred directly from medical records to an electronic database for subsequent analysis. No identifying personal health information was recorded.

Data Extraction

Demographic Data

Relevant demographic information was extracted from the medical record to capture both participant and injury characteristics. With regards to demographic characteristics, participants were primarily White or European American (i.e., 83.82%). A minority of the sample (i.e., 8.67%) identified as Hispanic/Latinx. The sample was 53.76% male. The sample age range included children between the ages of 10 and 18 ($M_{age} = 14.25$, $SD_{age} = 2.14$). For a complete summary of the sample demographics, see

Table 1. Over a third of the sample (i.e., 39.88%) previously sustained one or more concussions. Of note, individuals who were referred for a combined neuropsychological follow-up visit were more likely to report a history of concussion [$\chi^2(1, n = 173) = 7.09$, $p = .008$, Cramer's $V = 0.20$] and had significantly more lifetime concussions [$F(1, 171) = 11.70$, $p = .001$, $\eta_p^2 = 0.06$] than individuals who only completed an initial sports medicine visit. Almost half of the full sample (47.40%) had an existing medical/psychological diagnosis. The most common diagnosis was migraines (17.91%), followed by anxiety (15.60%), and ADHD (13.29%). Groups did not significantly differ based on rate of pre-existing diagnoses. Of note, previous concussion and medical/psychological history were self-reported.

With regards to injury characteristics, a majority of the sample did not experience LOC, retrograde or anterograde amnesia, or a concomitant orthopedic injury. The most common injury mechanism was sport-related (68.79%), followed by accidental falls (12.14%). Injury mechanism and characteristics did not significantly differ by groups. See Table 2 for a summary of full sample injury characteristics.

Table 1.

Sample Demographics

Characteristic	Full Sample (N = 173)	Group 1 (n = 99)	Group 2 (n = 74)	p-value
	Frequency/*M(SD)*	Frequency/*m(sd)*	Frequency/ *m(sd)*	
Race				0.08
European American/White	83.82%	78.79%	90.54%	
African American/Black	8.67%	12.12%	4.05%	
Asian American	0.58%	0.00%	1.35%	
Missing	6.94%	9.09%	4.05%	
Ethnicity				0.058
Non-Hispanic/Latinx	87.86%	83.84%	93.24%	
Hispanic/Latinx	8.67%	12.12%	4.05%	
Missing	3.47%	4.04%	2.70%	
Sex				0.03*
Male	53.76%	61.62%	43.24%	
Female	46.24%	38.38%	56.76%	
Existing Diagnosis				0.15
No	52.02%	57.58%	44.59%	
Yes	47.40%	42.42%	50.05%	
Missing	0.58%	0.00%	1.35%	
History of Concussion				0.002**
No	60.12%	68.69%	48.65%	
Yes (1 or More)	39.88%	31.31%	51.35%	
Number of Previous Concussions	0.76 (1.16)	0.51 (0.91)	1.09 (1.36)	0.001**
Age	14.25 (2.14)	14.43 (2.20)	12.23 (2.08)	0.536

Note *indicates significant group differences, $p < .05$, ** indicates $p < .01$.

Table 2.

Sample Injury Characteristics

Characteristic	Full Sample (N = 173)	Group 1 (n = 99)	Group 2 (n = 74)	p-value
	Frequency/*M(SD)*	Frequency/*m(sd)*	Frequency/*m(sd)*	
Injury Mechanism				0.055
SRC	68.79%	74.75%	60.81%	
MVC	7.51%	3.03%	13.51%	
Accidental fall	12.14%	10.10%	14.86%	
Assault	1.73%	1.01%	2.70%	
Other	6.94%	11.11%	8.10%	
LOC				1.00
No	88.44%	88.89%	87.84%	
Yes	11.56%	11.11%	12.16%	
Retrograde Amnesia				0.15
No	87.28%	90.91%	82.43%	
Yes	12.72%	9.09%	17.57%	
Anterograde Amnesia				0.25
No	90.17%	92.93%	86.49%	
Yes	9.83%	7.07%	13.51%	
OI				
No	94.80%	95.96%	93.24%	0.16
Yes	5.20%	4.04%	6.76%	
Time between injury and first date of service (days)	17.50 (23.10)	12.20 (11.01)	24.58(31.49)	.002**

Note. *indicates significant group differences, $p < .05$, ** indicates $p < .01$. SRC = sport related concussion; MVC = motor vehicle collision; LOC = loss of consciousness; OI = orthopedic injury

Symptom Report Data

At each CHW Concussion Clinic visit, patients completed the Post-Concussion Scale (PCS; Lovell & Collins, 1998; Lovell et al., 2006). The PCS is a 22-item measure of patients' current experience of common physiological (e.g., headaches), cognitive (e.g., difficulty concentrating), and emotional symptoms (e.g., irritability) associated with mTBI. The scale consists of a 7-point Likert scale ranging from 0 (i.e., no symptoms) to 6 (i.e., severe symptoms). Scores for the PCS include the total number of symptoms endorsed (i.e., rated 1 or higher) and the total symptom score (TSS), which consists of the sum of all ratings. Since symptom reporting is assessed at each contact, this variable was recorded longitudinally across visits.

The PCS was initially developed for use with amateur athletes. Items reflect symptoms commonly reported by athletes recovering from concussion. The PCS is administered as a component of the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) computerized neurocognitive assessment (Schatz et al., 2006) and as a standalone paper-and-pencil measure. Studies have demonstrated that the PCS has a high degree of internal consistency in both healthy samples (Cronbach alpha = .89-.94) and in samples of patients who have sustained concussion (Cronbach alpha = .92-.93; Lovell et al., 2006). With regards to construct validity, Pardini and colleagues (2004) proposed a four-factor structure, which included Somatic, Cognitive, Emotional, and Sleep dimensions. Many studies have indicated significant differences in item endorsement on the PCS between healthy and injured samples (Gioia et al., 2009; Lovell et al., 2006; Schatz et al., 2006). In general, participants report increased symptoms during the acute phase of injury recovery compared to their baseline report of symptoms, with a gradual decrease in symptom reporting over time. Most participants reported a baseline level of symptoms by 7-21 days post-injury (Blinman et al., 2009; Lovell et al., 2006, Schatz et al., 2006). Although most studies exploring the psychometric properties of the PCS utilize high school and collegiate athlete samples who sustained sport-related concussions, Blinman and colleagues (2009), used the measure with a sample of children as young as 11 years old with a mixed etiology of injuries.

Psychosocial Functioning

All patients were asked to estimate their subjective recovery and school participation at each visit to the CHW Concussion Clinic. Specifically, children were asked to rate their percentage of recovery on a scale from 0-100% and report how many days of school that they had missed since sustaining the injury. Similar to symptom reporting, these variables were assessed at each appointment and were, therefore, considered longitudinally.

Additionally, most patients who completed a combined visit with neuropsychology (90.54%) completed narrow-band measures of emotional functioning to screen for mood and anxiety symptoms. Based on age, patients complete the Children's Depression Inventory, Second Edition (CDI-2; Kovacs, 2011) or Beck Depression Inventory, Second Edition (BDI-II; Beck et al., 1996). Each of these scales measure self-reported symptoms of depression. Patients also complete the Revised Children's Manifest Anxiety Scale, Second Edition (RCMAS-2; Reynolds & Richmond, 2008) or the Beck

Anxiety Inventory (BAI; Beck et al., 1988) to rate their experience of symptoms of anxiety.

Neuropsychological Data

Each child referred for neuropsychological evaluation in the CHW Concussion Clinic completed an abbreviated, flexible neuropsychological test battery designed to sample multiple cognitive domains. Although certain cognitive domains (i.e., processing speed, working memory, executive functioning, estimated premorbid IQ, verbal memory) were reliably sampled across patients, specific test batteries varied as a function of age, primary complaint, and psychosocial history (e.g., preinjury diagnoses).

Each cognitive domain was sampled using published and well-validated clinical measures with appropriate normative samples (Lezak et al., 2012; Strauss et al., 2006). Most patients in this group (93.24%) completed the Wide Range Achievement Test, Fourth Edition (WRAT-4; Wilkinson & Robertson, 2006) Word Reading subtest to approximate premorbid intellectual functioning. Specifically, the WRAT-4 Word Reading subtest is a brief measure of single-word reading ability. The majority of participants also completed the Working Memory (97.30%) and Processing Speed Indices (95.95%) of the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003), Wechsler Intelligence Scale for Children, Fifth Edition (WISC-V; Wechsler, 2014), or the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV; Wechsler, 2008). The WISC-V Working Memory Index is comprised of Digit Span, a measure of basic attention and auditory working memory, and Picture Span, a measure of visual working memory. The WAIS-IV Working Memory Index consists of Digit Span and Arithmetic, a measure of auditory working memory and mental calculations, respectively. Both the WISC-V and WAIS-IV Processing Speed Indices contain the Coding and Symbol Search subtests, which measure psychomotor speed and visual scanning and speed of processing, respectively. The specific measure used was determined by the age of the participant and when the evaluation was completed.

Most individuals (86.47%) also completed various measures of executive functioning, which included subtests from the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001), including Trail Making, Verbal Fluency, and the Tower Test. These measures of executive functioning specifically assess visual scanning and cognitive flexibility, phonemic and semantic verbal production, and novel problem solving and planning, respectively. Alternatively, some patients (22.97%) completed Trail Making Test A & B (TMT; Reitan, 1955), a brief measure of visual scanning and cognitive flexibility. Memory was typically sampled using a brief verbal list-learning task, including the Wide Range Assessment of Memory and Learning, Second Edition (WRAML-2; Sheslow & Adams, 2003) Verbal Learning subtest or the Hopkins Verbal Learning Test, Revised (HVLT-R; Benedict et al., 1998). These tasks assess immediate verbal memory and delayed recall and recognition after a brief delay.

Additionally, while most patients completed the WRAML-2 Verbal Learning subtests, patients with visual memory complaints completed additional measures such as the Brief Visuospatial Memory Test, Revised (BVMT-R; Benedict et al., 1996). Further, when impaired scores were obtained in a specific cognitive domain, the clinician may have administered additional testing within the domain to document whether there was evidence of convergence across tasks. Few patients (9.46%) also completed the Test of Memory Malingering, Second Edition (TOMM-2; Tombaugh, 2000) a standalone PVT, based on suspect performance on Reliable Digit Span (RDS) from the WISC-IV, WISC-

V, or WAIS-IV (Kirkwood et al., 2011), an embedded PVT measure. RDS was calculated for 74.32% of patients.

Specific neuropsychological data varied across participants, reflecting both logistical constraints (e.g., patient demographic factors), performance levels, and clinical judgement. Given this variability, neuropsychological scores were aggregated across cognitive domains to allow for comparison across participants. Specific procedures used to aggregate scores are described in the Data Analysis section. Although some variability is inevitability lost in the aggregation process, aggregating neuropsychological scores is a well-accepted practice in the field (e.g., see Belanger et al., 2005). To facilitate comparison across measures, only standardized scores (i.e., age-corrected T-scores) are reported.

Medical Follow-Up/Service Utilization

Because the goals of the proposed project include evaluating whether initial symptoms predict the need for neuropsychological follow-up and whether neuropsychological/psychosocial functioning predicts further referral, information on service utilization was collected from medical records. Specifically, service utilization data included the number and type of appointments related to the patient's injury that were attended until the patient's last visit with providers from the CHW Concussion Clinic. Appointments were included if (1) they were documented in the medical record for acute care of the injury (e.g., emergency department visits, visits to primary care provider, etc.) or (2) they were follow-up visits or treatment referrals recommended by providers in the CHW Concussion Clinic. Visits that occurred before and after initial evaluation at the CHW Concussion Clinic were included in this data if they were related to the injury. Appointments were not included in the total if they occurred during this time frame but were related to the management of another health issue (e.g., visit to gastroenterology for management of pre-existing ulcers).

Data Analytic Plan

Statistical analyses were conducted in SPSS, version 26 (IBM Corporation, 2018). Given the exploratory nature of this project, data analyses were driven by the type of data extracted. Additionally, while primary analyses were conducted to evaluate each aim, ancillary analyses were also conducted to contextualize findings. Because this project utilized clinical data, missingness and other challenges impacted the feasibility of select data analyses. Specific analyses will be presented by aim.

Aim 1: *Describe a sample of patients presenting to a multidisciplinary concussion clinic and identify relevant factors that predict referral for neuropsychological evaluation and/or extended medical care status-post concussion*

To address the first primary aim, full sample characteristics and descriptive statistics were generated. To replicate the findings of Blinman and colleagues (2005) and McCarthy and Kosofsky (2015), data on the frequency of PCS symptoms endorsed at initial visit was calculated. Consistent with research suggesting that female patients tend to report more post-concussive symptoms than males (e.g., Iverson et al., 2015), a one-way analysis of variance (ANOVA) was completed to determine sex differences on initial symptom reporting. Additionally, a series of ANOVAs and Chi-square tests for independence were performed to determine initial differences between patients who completed sports medicine visits only (i.e., Group 1) and those who were ultimately referred for a combined follow-up visit with neuropsychology and sports medicine (i.e., Group 2). Welch tests and Games-Howell tests were used when equal variances were not assumed among groups. For analyses utilizing Chi-square tests with 2 by 2 tables, the

Yates' Continuity Correction was used to address overestimation of the resulting Chi-square value.

Additionally, direct logistic regression was performed to assess the simultaneous impact of select factors reported during the patients' first visit with sports medicine on the likelihood that patients would ultimately be referred for a follow-up combined visit. Given that referral for a combined visit reflects ongoing concerns for recovery, predictors established in the literature as being related to prolonged recovery were selected. Previous literature has suggested that female sex, initial symptom burden, and history of pre-morbid diagnoses predict prolonged symptom experience (Fehr et al., 2017; Iverson et al., 2015; Meehan et al., 2014). More recent research has also suggested that atypical recovery from concussion is associated with significant functional impairment (Simpson et al., 2017). As such, school participation was also considered. Sample size was considered in determining the appropriate number of predictor variables and in order to achieve adequate statistical power, using Tabachnick and Fidell's (2013) guidelines. Ultimately, the model contained five independent variables (i.e., history of existing diagnoses, participant sex, number of previous concussions, days of school missed, and Total Symptom Score at first visit).

Aim 2: *Document neuropsychological and emotional functioning, symptom report, and self-reported recovery in a sample of children referred for neuropsychological follow-up.*

To address the second primary aim, frequencies and descriptive statistics were generated to characterize clinical variables collected at the combined visit, including neuropsychological performance, emotional functioning, mTBI symptom reporting, and service utilization.

All neuropsychological data will be presented as age-corrected T-scores (i.e., *M* = 50, *SD* = 10) to allow for aggregation and comparison across measures. Raw data were converted to age-corrected scores utilizing published normative data. If necessary, age corrected Scaled Score were converted to T-scores then aggregated with theoretically similar measures. For example, Trails A and B scores were aggregated with D-KEFS Trail Making Test trials.[4] Age-corrected scaled scores for each measure were converted to T-scores, and these variables were combined into one variable. A composite score, consisting of the average of all trail making scores, was then generated. A similar process was used to generate composite scores for processing speed (i.e., consisting of aggregated scores from the WISC-IV, WISC-V, and WAIS-IV PSI indices), working memory (i.e., consisting of aggregated scores from the WISC-IV, WISC-V, and WAIS-IV WMI), verbal memory recall, and verbal memory recognition scores (i.e., consisting of aggregated scores from the WRAML-2 List Learning and HVLT-R tasks). For instances in which a cognitive domain was only assessed using one measure across participants (i.e., BVMT-R Visual Memory and D-KEFS Verbal Fluency), the composite score reflects an average of performance across all trials of the singular measure. Additionally, a general neuropsychological composite was derived, which included the average performance across all measures assessed.

Performance validity was also considered in the interpretation of neuropsychological scores. Consistent with published guidelines, patients were considered to have suspect performance validity if they obtained a Reliable Digit Span score of less than 7 on WAIS-IV (Axelrod et al., 2006) or less than 6 on the WISC-IV or

[4] Appendix A presents correlations across tasks and the pattern of convergent and divergent validity supports the decision to generate composite scores reflecting respective cognitive constructs.

WISC-V (Kirkwood et al., 2011), and/or if they obtained a score of less than 45 on Trial 1 and/or Trial 2 of the TOMM (Tombaugh, 1997). Although adult practice guidelines recommend considering both embedded and standalone PVT measures (Heilbronner et al., 2009), the decision to exclude participants based on failure of *either* a standalone or embedded measure was made to take a more conservative approach to identifying those with suspect validity. Based on these criteria, six participants were identified as having suspect performance validity. Of note, four of the six participants failed both embedded and standalone PVT measures. Given previous research suggesting that non-credible neuropsychological performance is related to post-concussive symptom endorsement (e.g., Arujo et al., 2014, Kirkwood et al., 2014), patients with suspect performance were identified and removed prior to conducting sensitivity analyses (i.e., analyses were conducted before and after the removal of patients with suspect performance).

Descriptive statistics were generated, as well as the rate at which patients obtained impaired scores. Based on current pediatric neuropsychology consensus guidelines (i.e., see Guilmette et al., 2020), any score below the broadly average range (e.g., low average to high average, $T < 37$) was considered "impaired." To explore the relationship between neuropsychological performance and symptom reporting, correlations among aggregated scores in each domain and symptom reporting at initial and combined visits were generated.

Additionally, a series of repeated-measures ANOVAs were conducted to explore differences in self-reported recovery measures (e.g., PCS TSS, total number of PCS symptoms, self-reported recovery rating) between initial and follow-up combined visits. Consistent with full-sample analyses calculated in Aim 1 and previous research suggesting sex differences in PCS symptom reporting (Iverson et al., 2015), the frequency of PCS symptoms reported was calculated, as well as ANOVAs, to delineate mean-level sex differences in number and intensity of symptom reporting.

Emotional functioning data gathered from self-report measures of anxiety and depression were also considered. Emotional functioning data will be presented in age-corrected T-scores where available; however, data were collected such that only raw scores and qualitative descriptors were available for the BDI and BAI. As such, emotional functioning data were aggregated to reflect the percentage of the sample who endorsed clinically significant symptoms of anxiety and/or depression. Those who endorsed either a "moderate" or "severe" degree of symptoms on the BDI and/or BAI, as well as children and adolescents who endorsed total T scores at or above the 95^{th} percentile (i.e., $T > 65$) on the RCMAS and or CDI were considered to have clinically significant emotional functioning symptoms.

In addition to the primary analyses associated with Aim 2, ancillary analyses were conducted to evaluate whether mTBI and comorbid emotional symptoms result in more impaired neuropsychological functioning relative to mTBI alone in the post-acute stage of recovery. A series of ANOVAs were conducted to determine whether patients with clinically significant emotional symptoms differed in their neuropsychological performance across domains.

Ancillary analyses were also conducted to explore how variables across time points were associated with neuropsychological functioning. A multiple linear regression was calculated to predict aggregated neuropsychological score based on a number of factors reported during patients' initial visit with sports medicine. Per Tabachnick and Fidell's (2013) guidelines, the number of independent predictor variables did not exceed three for any multiple regression conducted using data from Group 2 based on the sample size. The model contained three independent variables, including TSS at initial visit, number of previous concussions, and number of school days missed at initial visit. Predictor variables were selected based on relevant variables that were identified as predictive in whole sample logistic regression analyses in Aim 1.

Aim 3: *Identify factors that predict the need for extended management of symptoms based upon neuropsychological performances and symptom reporting.*

To further understand the relationship among variables in Group 2 and medical service utilization (i.e., the number of visits associated with the injury), a multiple linear regression was calculated to predict total number of visits related to injury based on number of previous diagnoses, TSS at initial visit, and aggregated neuropsychological functioning. Given limited existing research on medical service utilization in patients who experience prolonged recovery from concussion, analyses were exploratory in nature. Consistent with Jimenez and colleagues' (2017) findings that pre-injury psychiatric diagnoses predicted post-injury service utilization patterns, number of previous diagnoses was selected as a predictor variable. Given that initial symptom burden is a known predictor of long-term outcomes as well (Fehr et al., 2017; Iverson et al., 2017), TSS at initial visit was also identified as an independent variable. Finally, neuropsychological functioning was selected as a predictor variable because it was thought that cognitive concerns identified on neuropsychological evaluation would contribute to appropriate therapeutic referrals.

Results

General Overview

Results relevant to each aim and associated supplemental analyses will be presented sequentially. Given that not all participants completed a combined visit and performance-based measures varied as a function of age and presenting problems, sample sizes vary by aim and analysis.

Aim 1: *Describe a sample of patients presenting to a multidisciplinary concussion clinic and identify relevant factors that predict referral for neuropsychological evaluation and/or extended medical care status-post concussion.*

Full sample characteristics at the initial visit are described in Table 1. With regards to demographic differences, Chi-square tests of independence revealed that groups differed in terms of participant sex. Patients referred for a neuropsychological evaluation (Group 2) were more likely to be female [Yates continuity corrected $\chi^2(1, n = 173) = 5.04$, $p = .03$, Cramer's $V = 0.18$]. Additionally, individuals in Group 2 were more likely to report a history of sustaining at least one prior concussion [$\chi^2(1, n = 173) = 7.09$, $p = .008$, Cramer's $V = 0.20$]. Groups also significantly differed in terms of duration of time between injury and first date of service. Individuals in Group 2 had a significantly longer duration between injury and date of first visit to the CHW Concussion Clinic [Welch's $F(1, 86.40) = 10.48$, $p = .002$, $\eta_p^2 = 0.11$]. For a summary of sample characteristics and group differences, see Tables 1 and 2.

Significant group differences were also observed on self-reported injury functioning variables. Patients referred for a neuropsychological evaluation (Group 2) endorsed significantly more PCS symptoms at their first appointment than those who were not [Welch's $F(1, 166.16) = 19.81$, $p = .000$, $\eta_p^2 = 0.11$]. Their ratings also yielded significantly higher PCS TSS, suggesting a greater degree of symptom intensity [$F(1, 171) = 16.10$, $p = .000$, $\eta_p^2 = 0.09$]. Additionally, patients in Group 1 rated their self-reported recovery as significantly greater than those in Group 2 [$F(1, 163) = 10.87$, $p = .001$, $\eta_p^2 = 0.06$]. Patients in Group 2 also reported that they missed significantly more school days due to their injury [Welch's $F(1, 130.24) = 14.16$, $p = .000$, $\eta_p^2 = 0.10$). Patients in Group 2 also completed significantly more medical visits related to their injury compared to those in Group 1 [Welch's $F(1, 95.64) = 63.62$, $p = .000$, $\eta_p^2 = 0.40$]. Patients in Group 1 were most likely to complete PCP (39.39%), PT (37.37%), and ED visits (33.33%). Participants in Group 2 were most likely to complete PT (71.62%), neuroimaging (66.22%), and PCP (59.46%) visits. For a full summary of frequencies of follow-up visits, see Table 3.

Table 3.

Mean-Level Group Differences

Variable	Full Sample (*N* = 173)	Group 1 (*n* = 99)	Group 2 (*n* = 74)	p-value
	M(SD)	*m(sd)*	*m(sd)*	
TSS at initial visit	26.83 (22.00)	21.26 (20.48)	34.27 (21.89)	.000*
Total PCS symptoms endorsed at initial visit	9.75 (5.82)	8.16 (5.81)	11.88 (5.14)	.000*
Self-reported recovery rating at initial visit	65.36 (24.30)	70.50 (23.10)	58.22 (24.29)	.002*
Number of missed school days	2.98 (3.21)	2.20 (2.74)	4.07 (3.49)	.000**
Total Number of Visits Related to Concussion	9.22 (8.03)	5.36 (4.12)	14.38 (9.05)	.000**
Sports Medicine	2.75 (1.42)	2.23 (1.03)	3.46 (1.56)	
Neuropsychology	0.47 (0.59)	0.00 (0.00)	1.11 (0.31)	
Physical Therapy	2.75 (3.67)	1.44 (2.26)	4.49 (4.42)	
Imaging	0.55 (0.66)	0.35 (0.54)	0.82 (0.71)	
Primary Care	0.72 (0.96)	0.57 (0.85)	0.92 (1.07)	
Psychology	1.59 (3.66)	0.44 (1.30)	3.12 (5.00)	
Emergency Department	0.39 (0.53)	0.34 (0.5)	0.45 (0.58)	
Time between injury and last date of service (days)	102.98 (113.31)	53.02 (48.65)	169.15 (138.36)	.000*

Note. * indicates statistically significant group differences, $p < .05$, **indicates $p < .01$.
TSS = Total Symptom Score; PCS = Post-Concussion Scale

With respect to symptoms reported, the most common symptom reported on the PCS at initial visit was headache, which was endorsed by 80.34% of the sample.

Difficulty concentrating and sensitivity to noise were the next most commonly reported symptoms, with 68.79% and 68.21% of the sample endorsing these symptoms, respectively. See Table 4 for a complete summary of symptom frequency data. Of note, symptom reporting at initial visit significantly differed by sex. Specifically, female patients endorsed significantly more symptoms [$F(1, 171) = 7.40$, $p = .007$, $\eta_p^2 = 0.04$] and a greater degree of symptom intensity (i.e., TSS) [$F(1, 171) = 9.72$, $p = .002$, $\eta_p^2 = 0.05$] than male patients at initial visit.

Table 4.

Post-Concussion Scale (PCS) Symptoms at Initial Visit

Symptom	Full Sample (N = 173)		Male Patients (n = 93)		Female Patients (n = 80)	
	%	*M* (*SD*)	%	*m* (*sd*)	%	*m (sd)*
Headaches	80.34	2.42 (1.69)	74.19	2.06 (1.71)	87.25	2.84 (1.59)
Nausea	36.99	0.86 (1.42)	31.18	0.66 (1.25)	43.75	1.10 (1.56)
Vomiting	2.89	0.41 (0.25)	1.08	0.03 (0.23)	3.75	0.50 (0.27)
Balance Problems	47.97	1.13 (1.54)	44.08	0.95 (1.36)	52.50	1.35 (1.71)
Dizziness	59.54	1.51 (1.69)	48.39	1.18 (1.57)	72.50	1.89 (1.76)
Trouble Falling Asleep	47.97	1.46 (1.86)	39.78	1.02 (1.53)	57.50	1.98 (2.07)
Sleeping More than Usual	49.71	1.57 (1.92)	44.09	1.41 (1.85)	56.25	1.78 (2.01)
Sleeping Less than Usual	19.65	0.61 (1.41)	16.13	0.41 (1.11)	23.75	0.84 (1.67)
Sensitivity to Light	72.25	1.94 (1.66)	61.29	1.52 (1.60)	85.00	2.44 (1.61)
Sensitivity to Noise	68.21	1.86 (1.71)	60.21	1.46 (1.56)	77.50	2.31 (1.76)
Irritability	52.60	1.34 (1.64)	52.68	1.19 (1.49)	52.50	1.53 (1.80)
Sadness	23.12	0.63 (1.34)	19.35	0.52 (1.26)	27.50	0.76 (1.43)
Nervousness	28.90	0.79 (1.47)	20.58	0.56 (1.27)	36.25	1.05 (1.65)
Feeling More Emotional	35.26	0.91 (1.51)	30.11	0.74 (1.27)	41.25	1.11 (1.67)
Numbness or Tingling	20.23	0.40 (0.93)	18.28	0.29 (0.70)	22.50	0.54 (1.12)
Feeling Slowed Down	57.80	1.63 (1.80)	52.69	1.51 (1.80)	63.75	1.78 (1.80)
Feeling Mentally Foggy	59.54	1.68 (1.80)	53.76	1.41 (1.68)	66.25	2.00 (1.90)
Difficulty Concentrating	68.79	2.15 (1.66)	62.37	1.82 (1.80)	76.25	2.54 (1.89)

Symptom (continued)	Full Sample ($N = 173$)		Male Patients ($n = 93$)		Female Patients ($n = 80$)	
	%	*M* (*SD*)	%	*m (sd)*	%	*m (sd)*
Difficulty Remembering	45.66	1.22 (1.66)	41.93	1.06 (1.55)	50.00	1.41 (1.78)
Fatigue	64.16	1.91 (1.90)	61.29	1.73 (1.86)	67.50	2.11 (1.94)
Visual Disturbance	34.68	0.83 (1.42)	30.11	0.58 (1.12)	40.00	1.11 (1.68)
Total Symptoms Endorsed	-	9.75 (5.82)	-	8.66 (5.78)	-	11.03 (5.62)
TSS	-	26.83 (22.00)	-	22.11(19.24)	-	32.21 (23.80)

Note. All items are scored on a scale from 0-6, with ratings of 1 or more reflecting symptom endorsement. TSS = Total Symptom Score

Direct logistic regression was performed to assess the simultaneous impact of five independent variables (i.e., history of existing diagnoses, participant sex, number of previous concussions, days of school missed, and TSS at first visit). Collinearity statistics indicated that correlations among variables did not exceed 0.65. The full model containing all predictors was statistically significant, $\chi^2(5, N = 169) = 38.34$, $p = .000$, indicating that the model was able to distinguish between participants who did and did not complete a follow-up combined visit. The model as a whole explained between 20.3% (Cox and Snell R square) and 27.3% (Nagelkerke R squared) of the variance in completion of a combined visit and correctly classified 68% of cases. As shown in Table 5, only four of the independent variables made a unique statistically significant contribution to the model (i.e., number of previous concussions, TSS, participant sex, and number of school days missed). The strongest predictor of completion of a combined visit was participant sex, indicating that female patients were 2.07 times more likely to complete a combined visit than male patients.

Table 5.

Logistic Regression Analysis Results

Variable	*B*	SE	Wald	Sig. (*p*)	Exp(*B*)	95% CI
1. History of existing diagnosis	0.02	0.36	0.00	0.949	1.02	0.51-2.08
2. Total symptom score at initial visit	0.02	0.01	5.76	0.016*	1.02	1.00-1.04
3. Number of previous concussions	0.61	0.18	10.90	0.001**	1.83	1.28-2.62
4. Number of school days missed	0.17	0.06	8.60	0.003**	1.18	1.06-1.32
5. Participant sex	0.73	0.36	4.08	0.043*	2.07	1.02-4.20

Note. *indicates significant group differences, $p < .05$, ** indicates $p < .01$

Aim 2: *Document neuropsychological and emotional functioning, symptom report, and self-reported recovery in a sample of children referred for neuropsychological follow-up.*

Sample characteristics and descriptive statistics for data gathered at the initial visit for Group 2 is presented in Table 1. Patients completed their respective neuropsychological evaluation approximately 40 days after their initial visit with sports medicine; however, there was significant variability between initial and follow up visits (i.e., $sd = 31.97$, minimum = 8, maximum = 174).

With regards to symptom reporting during the neuropsychological evaluation, the most commonly endorsed symptom on the PCS across patients was difficulty concentrating (i.e., endorsed by 63.51% of the sample). Headache and sensitivity to light were the next most commonly reported symptoms, endorsed by 60.81 and 55.41%, respectively. Similar to results presented in Aim 1, female patients reported significantly more PCS symptoms [Welch's $F(1, 72) = 4.66$, $p = .034$, $\eta_p^2 = 0.06$] and a greater TSS [Welch's $F(1, 72) = 4.79$, $p = .000$, $\eta_p^2 = 0.06$] than male patients at combined visit. Summaries of PCS symptoms at the combined visit with neuropsychology are described in Table 6.

Table 6.

Post-Concussion Scale (PCS) Symptoms at Combined Visit with Neuropsychology

Symptom	Full Sample (*n* = 74)		Male Patients (*n* = 32)		Female Patients (*n* = 42)	
	%	*M* (*SD*)	%	*m (sd)*	%	*m* (*sd*)
Headaches	60.81	1.45 (1.55)	40.63	0.75 (1.08)	76.19	1.98 (1.65)
Nausea	20.27	0.47 (1.02)	12.50	0.28 (0.81)	26.19	0.62 (1.15)
Vomiting	1.35	0.01 (0.12)	3.13	0.03 (0.18)	0.00	0.00 (0.00)
Balance Problems	40.54	1.04 (1.57)	25.00	0.50 (1.02)	52.38	1.45 (1.80)
Dizziness	44.59	1.15 (1.69)	25.00	0.53 (1.29)	59.52	1.62 (1.81)
Trouble Falling Asleep	32.43	0.77 (1.42)	21.88	0.41 (1.13)	40.48	1.05 (1.56)
Sleeping More than Usual	33.78	0.76 (1.29)	28.13	0.50 (0.92)	38.10	0.95 (1.50)
Sleeping Less than Usual	20.27	0.55 (1.29)	6.25	0.16 (0.72)	30.95	0.86 (1.54)
Sensitivity to Light	55.41	1.18 (1.49)	46.88	0.75 (1.02)	61.90	1.50 (1.71)
Sensitivity to Noise	50.00	1.11 (1.48)	34.38	0.56 (0.98)	61.90	1.52 (1.66)
Irritability	52.70	1.19 (1.58)	40.63	0.84 (1.27)	52.38	1.45 (1.74)
Sadness	24.32	0.59 (1.23)	18.75	0.41 (0.98)	28.57	0.74 (1.38)
Nervousness	31.08	0.85 (1.49)	21.88	0.44 (1.05)	38.10	1.17 (1.71)
Feeling More Emotional	54.17	0.74 (1.23)	25.00	0.38 (0.79)	42.86	1.02 (1.44)
Numbness or Tingling	17.57	0.43 (1.09)	6.25	0.06 (0.25)	26.19	0.71 (1.37)
Feeling Slowed Down	50.00	1.20 (1.52)	43.75	0.78 (1.13)	54.76	1.52 (1.70)
Feeling Mentally Foggy	44.59	1.27 (1.73)	31.25	0.72 (1.30)	54.76	1.69 (1.91)
Difficulty Concentrating	63.51	1.59 (1.66)	62.50	1.09 (1.09)	64.29	1.98 (1.92)

Symptom (Continued)	Full Sample (*n* = 74)		Male Patients (*n* = 32)		Female Patients (*n* = 42)	
	%	*M* (*SD*)	%	*m (sd*)	%	*m* (*sd*)
Difficulty Remembering	52.70	1.18 (1.49)	50.00	0.69 (0.86)	54.76	1.55 (1.74)
Fatigue	44.59	1.20 (1.63)	31.25	0.69 (1.23)	54.76	1.60 (1.80)
Visual Disturbance	31.08	0.65 (1.22)	21.88	0.28 (0.58)	38.10	0.93 (1.49)
Total Symptoms Endorsed	-	9.75 (5.82)	-	5.94 (5.29)	-	9.60 (6.61)
TSS	-	26.82 (22.00)	-	10.91 (14.32)	-	25.95 (24.46)

Note. All items are scored on a scale from 0-6, with ratings of 1 or more reflecting symptom endorsement. TSS = Total Symptom Score

Differences between key variables (i.e., total PCS symptoms endorsed, TSS, and self-rated recovery) at both time points were also considered. Repeated measures ANOVAs indicated that, compared to their initial visit, patients reported a significant reduction in the number of symptoms [Wilks' Lambda = -0.63, $F(1, 73) = 43.70$, $p = .000$] and symptom intensity [Wilks' Lambda = 0.63, $F(1, 73) = 42.97$, $p = .000$] as well as significantly higher self-reported recovery [Wilks' Lambda = 0.53, $F(1, 67) = 58.52$, $p = .000$] at their neuropsychological evaluation compared to their initial appointment with sports medicine. For a complete summary of mean differences between time points, see Table 7.

Table 7.

Mean-Level Differences Between Initial and Combined Visit with Neuropsychology

Variable	Initial Visit (*n* = 74)	Combined Visit (*n* = 74)	*p*-value	η_p^2
	m (sd)	*m (sd)*		
TSS	34.27 (24.45)	19.45 (21.89)	.000**	0.37
Total PCS symptoms endorsed	11.88 (5.13)	8.01 (6.30)	.000**	0.37
Percent recovery	58.34 (23.45)	79.74 (21.09)	.000**	0.47

Note. **indicates statistically significant group differences, $p < .01$. TSS = Total Symptom Score; PCS = Post-Concussion Scale

When considering the entire sample of patients who completed neuropsychological testing, estimated premorbid intellectual functioning (i.e., WRAT-4 Word Reading T-score *m* = 53.79) and neuropsychological performance across participants was in the average range (i.e., T-scores ranging from 49.58 to 53.10). When considering the entire sample of individuals who completed neuropsychological testing, rates of obtaining impaired scores varied from 3.03% (Verbal Memory- Delayed Recall) to 13.36% (Verbal Memory- Delayed Recognition) across measures. After excluding participants with suspect performance validity, the rate of impaired scores ranged from 0.00% (Working Memory) to 8.20% (Verbal Memory- Delayed Recognition) across measures. For a complete summary of neuropsychological performance descriptive statistics both including and excluding participants with suspect engagement, see Table 8.

Table 8.

Summary of Composite T-Scores

Composite Measure	Full Sample			Suspect Validity Excluded (*n* = 6)		
	n	*m* (*sd*)	Percent Impaired	*n*	*m* (*sd*)	Percent Impaired
Total Composite	73	50.96 (6.87)	4.11%	68	52.07 (5.33)	0.00%
Trail Making	64	51.71 (7.67)	4.69%	61	52.23 (7.17)	2.94%
Processing Speed	71	49.58 (9.34)	5.63%	67	50.12 (8.64)	2.98%
Working Memory	72	51.08 (9.99)	4.17%	68	52.26 (8.74)	0.00%
Verbal Memory (Immediate Recall)	66	52.42 (10.53)	7.58%	61	53.81 (9.31)	3.27%
Verbal Memory (Delayed Recall)	66	53.24 (7.93)	3.03%	61	54.58 (9.06)	1.63%
Verbal Memory (Delayed Recognition)	66	50.31 (10.96)	13.36%	61	51.77 (9.54)	8.20%
Verbal Fluency	58	52.73 (7.93)	3.44%	55	53.42 (7.10)	0.00%
Visual Memory	18	50.56 (8.70)	5.56%	17	52.22 (5.27)	0.00%

Note. All composite scores are presented in T-scores (*M* = 50, *SD* = 10)

The relationship between reported PCS symptoms and suboptimal performance validity was also explored. When considering all patients who completed a neuropsychological evaluation, significant generally medium negative correlations were observed between initial TSS and aggregated trail making (r = -0.31), processing speed (r = -0.30), working memory (r = -0.43), and verbal memory (r = -0.25) scores. A similar pattern of negative correlations was observed between TSS obtained during the combined follow-up visit with neuropsychology and trail making (r = -0.43), processing speed (r = -0.25), and working memory (r = -0.34) scores. In contrast, when six patients with suspect performance validity were excluded, significant generally medium associations were only observed between initial TSS and trail making (*r* = -0.28) and working memory (*r* = -0.40) scores. Significant associations were also observed between these same variables at the combined visit (e.g., *r* = -0.42 and *r* = -0.29, respectively). For a complete summary of correlations between TSS and neuropsychological performance, see Table 9.

Table 9.

Correlation Between Symptoms and Aggregated Scores

	Full Sample (Group 2)		Suspect Validity Excluded (*n* = 6)	
Composite Measure	TSS at Initial Visit	TSS at Combined Visit	TSS at Initial Visit	TSS at Combined Visit
	Pearson's *r*	Pearson's *r*	Pearson's *r*	Pearson's *r*
Trail Making	-0.31*	-0.43**	-0.28*	-0.42**
Processing Speed	-0.30*	-0.25*	-0.20	-0.12
Working Memory	-0.43*	-0.34**	-0.40**	-0.29*
Verbal Memory (Immediate Recall)	-0.11	-0.22	0.03	-0.04
Verbal Memory (Delayed Recall)	-0.05	-0.18	0.07	-0.06
Verbal Memory (Delayed Recognition)	-0.25*	-0.21	-0.14	-0.01
Verbal Fluency	-0.12	-0.09	-0.07	-0.08
Visual Memory	-0.45	-0.38	-0.39	-0.03

Note. * indicates statistically significant Pearson correlations, $p < .05$, ** indicates $p < .01$. TSS = Total Symptom Score

Sixty-nine patients who completed a neuropsychological evaluation also completed questionnaires specific to emotional functioning. Of this subset of patients, 23.18% endorsed clinically significant symptoms of anxiety and/or depression. Patients were considered to have significant emotional functioning concerns if they endorsed clinically significant symptoms of anxiety and/or depression[5]. Patients who endorsed clinically significant levels of anxiety and/or depression performed significantly worse than patients without clinically significant emotional functioning concerns on aggregated measures of processing speed [$F(1, 64) = 13.20$, $p = .001$, $\eta_p^2 = 0.17$], verbal fluency [$F(1, 56) = 8.47$, $p = .005$, $\eta_p^2 = 0.13$], and verbal memory delayed recognition [$F(1, 64) = 7.28$, $p = .009$, $\eta_p^2 = 0.10$]. Groups did not significantly differ on measures of working memory or other aspects of executive functioning, verbal memory, or visual memory. Group differences were also examined after those with suspect performance validity were excluded. Despite their removal from analyses, the same pattern of between-group differences emerged on aggregated measures of processing speed [$F(1, 60) = 7.31$), $p = .008$, $\eta_p^2 = 0.11$], verbal fluency [$F(1,53) = 7.24$, $p = .009$, $\eta_p^2 = 0.12$], and verbal memory delayed recognition [$F(1, 59) = 5.05$, $p = .028$, $\eta_p^2 = 0.08$]. For a summary of group differences with and without individuals with suspect performance validity, see Table 10.

[5] Anxiety and depression were considered simultaneously due to the small sample size and disparity between those who endorsed significant symptoms of anxiety only (5.88%) compared to those who endorsed significant symptoms of depression only (47.06%) and those who endorsed clinically significant symptoms of both anxiety and depression (47.06%)

Table 10.

Mean Neuropsychological Functioning Differences When Considering Emotional Functioning and Performance Validity

Composite Measure	Full Sample			Suspect Validity Excluded (*n* = 6)		
	Controls	Clinically Significant Emotional Concerns	*p*-value	Controls	Clinically Significant Emotional Concerns	*p*-value
	m (*sd*)	*m* (*sd*)		*m* (*sd*)	*m* (*sd*)	
Trail Making	52.84 (6.44)	48.00 (10.15)	.099	53.06 (6.48)	49.43 (8.83)	.096
Processing Speed	52.07 (8.22)	42.98 (9.48)	.001**	52.37 (8.24)	45.54 (7.17)	.008**
Working Memory	52.39 (8.42)	48.71 (14.44)	.209	53.02 (7.97)	52.10 (11.52)	.731
Verbal Memory (Immediate Recall)	53.64 (9.38)	48.62 (13.16)	.098	54.41 (9.05)	51.81 (10.24)	.363
Verbal Memory (Delayed Recall)	54.56 (9.34)	49.13 (9.33)	.063	55.46 (8.87)	51.62 (9.39)	.166
Verbal Memory (Delayed Recognition)	52.28 (9.69)	44.17 (12.68)	.009**	53.22 (8.73)	46.90 (10.81)	.009**
Verbal Fluency	54.34 (7.21)	47.68 (8.22)	.005**	54.78 (6.72)	49.04 (6.73)	.009**
Visual Memory	52.88 (5.16)	42.42 (8.70)	.237	52.88 (5.15)	49.11 (5.27)	.274

Note. * indicates statistically significant difference, $p < .05$, ** indicates $p < .01$

Patients who endorsed clinically significant symptoms of anxiety and/or depression endorsed significantly higher TSS scores at their initial visit [$F(1, 67) = 13.62$, $p = .000$, $\eta_p^2 = 0.16$] and during their neuropsychological evaluation, Welch's $F(1, 20.93)$

= 11.52 p = .003, $\eta_p^2 = 0.36$. Patients who endorsed clinically significant emotional symptoms did not differ from other patients in terms of days of school missed, self-reported recovery rating at either visit, total number of visits related to concussion, or total number of psychology visits. See Table 11 for a summary of between-group differences.

Table 11.

Mean Differences Between Participants with Clinically Significant Emotional Concerns Compared to Non-Clinically Significant Controls

Variable	Emotional Concerns Within Normal Limits	Clinically Significant Emotional Concerns	*p*-value
	m(*sd*)	*m*(*sd*)	
TSS at Initial Visit	28.31 (18.76)	48.65 (22.52)	.000**
TSS at Combined Visit	12.83 (17.12)	34.29 (25.47)	.003**
Total Number of Visits	12.23 (8.03)	14.71 (7.59)	.508
Total Number of Psychology Visits	2.87 (4.82)	2.41 (3.06)	.717
Number of School Days Missed	3.72 (0.52)	3.19 (0.77)	.508
Self-Reported Recovery Rating at Initial Visit	60.94 (24.81)	51.76 (23.04)	.185
Self-Reported Recovery Rating at Combined Visit	81.53 (20.66)	74.31 (21.67)	.233

Note. ** indicates statistically significant difference, $p < .01$

Finally, a multiple linear regression was calculated to predict aggregated neuropsychological score based on factors reported during patients' initial visit with sports medicine. The model contained three independent variables, including TSS at initial visit, number of previous concussions, and number of school days missed prior to the initial visit. The full model containing all predictors was statistically significant, $F(3, 67) = 3.99$, $p = .011$. The model as a whole explained 15.20% of the variance in performance across neuropsychological measures. As shown in Table 12, only one of the independent variables, TSS at initial visit, made a unique statistically significant contribution to the model (Beta = -0.34, $p = .006$). The model suggests that initial symptom reporting uniquely explains 10.37% of the variance in neuropsychological performance at follow-up visit. Notably, after excluding participants putting forth suspect effort, the model was no longer statistically significant, $F(3, 63) = 2.41$, $p = .076$.

Table 12.

Multiple Regression Analysis Results

Variable	*B*	SE	β	*T*	Sig. (*p*)	95% CI
1. TSS (Initial Visit)	-0.12	0.04	-0.34	-2.87	0.006**	-0.20- -.0.04
2. Number of Previous Concussions	0.05	0.62	0.01	0.08	0.939	-1.18-1.27
3. Number of School Days Missed	-0.22	0.25	-0.10	-0.87	0.389	-0.73-0.29

Note. ** indicates statistically significant predictor variable, $p < .01$. TSS = Total Symptom Score

Aim 3: *Identify factors that predict the need for extended management of symptoms based upon neuropsychological performances and symptom reporting.*

A multiple linear regression with three independent factors (i.e., number of previous diagnoses, TSS at initial visit, and aggregated neuropsychological functioning) was calculated to predict total service utilization. The full model containing all predictors was statistically significant, $F(3, 68) = 3.85$, $p = .013$. The model as a whole explained 14.50% of the variance in medical service utilization.[6] As indicated in Table 13, only one of the independent variables, TSS at initial visit, made a unique, statistically significant contribution to the model (Beta = .38, $p = .003$). This model suggests that TSS uniquely explains 12.18% of the variance in number of visits related to injury.

Table 13.

Multiple Regression Analysis Results

Variable	B	SE	β	*T*	Sig. (*p*)	95% CI
1. Number of Existing Diagnoses	-0.31	0.86	-0.04	-0.36	0.718	-2.03-1.41
2. TSS at Initial Visit	0.14	0.04	0.38	3.12	0.003**	0.05-0.23
3. Neuropsychological Composite Score	-0.02	0.14	-0.02	-0.15	0.881	-0.30-0.26

Note. ** indicates statistically significant predictor, $p < .01$. TSS = Total Symptom Score

[6] Regression analyses were also conducted when excluding individuals with suspect performance validity. While 5 participants were removed from analyses, overall results remained the same $F(3, 63) = 2.59$, $p = .018$. TSS at initial visit remained the only unique, statistically significant contribution to the model (Beta = 0.35, $p = .005$).

Discussion

Despite the ubiquity of mTBI in children, it remains challenging to understand and predict recovery for many. While most individuals recover quickly and completely, a small but significant minority of individuals experience protracted recovery from mTBI (Barlow et al., 2010; Rohling et al., 2012; Ruff et al., 1996; Ruff, 2005). Extensive research with adults has elucidated that both pre-injury and injury-related factors influence recovery. Consistent with the adult literature, much of the pediatric literature has attempted to clarify whether atypical recovery is related to psychogenic or physiogenic factors (Peterson et al., 2015); however, studies simultaneously considering these variables suggest that recovery is likely best understood through a biopsychosocial model (Conder & Conder, 2015; McCrea et al., 2009; Silverberg & Iverson, 2011). It is clear that children who experience prolonged recovery experience significant functional impairment (Moran et al., 2011; Pieper & Garavan, 2015; Simpson et al., 2017); however, less is known about the impact of protracted recovery on health care utilization. Given these observations, the goal of this project was to comprehensively consider variables relevant to recovery from pediatric concussion, including pre-injury diagnoses, symptom burden, neuropsychological and emotional functioning, performance validity, and medical/psychological service utilization in a sample of patients experiencing prolonged recovery from concussion.

A primary aim of this research was to describe a sample of patients presenting to a multidisciplinary concussion clinic and identify relevant factors that predicted referral for more specialized follow-up. Those ultimately referred for a combined visit with neuropsychology and sports medicine were thought to reflect patients either already experiencing or at increased risk for experiencing prolonged recovery. Descriptive statistics and mean-level group differences indicated that although groups were similar with regard to age and injury-related variables, individuals referred for a combined neuropsychological visit (i.e., Group 2) had a significantly higher proportion of female patients to male patients, a significantly higher rate of history of at least one previous concussion, and a significantly longer duration between date of injury and date of first visit compared to those who only completed an initial visit with sports medicine (i.e., Group 1). On average, patients in Group 2, were nearly 25 days out from injury when they completed their initial visit, while those in Group 1 were approximately 12 days out from injury. This discrepancy in large part reflects that individuals in Group 2 were still experiencing symptoms while approaching or beyond the typical recovery window of approximately one-month status-post injury (Barlow et al., 2015).

Additionally, groups differed significantly with regards to initial symptom burden, self-reported recovery rating, and school absenteeism, suggesting that those in Group 2 reported more subjective distress and experienced more functional impairment compared those in Group 1. Consistent with previous research (e.g., Blinman et al., 2009; Iverson et al., 2015, McCarthy & Kosofsky, 2015), headache was the most commonly endorsed symptom across patients, followed by difficulty concentrating and sensitivity to noise. In addition, female patients endorsed significantly more symptoms than male patients at their initial visit.

Similarly, logistic regression analysis suggested that a model including number of previous concussions, TSS, participant sex, and days of school missed significantly predicted whether participants were referred for a follow-up combined visit with neuropsychology. Results indicated that participant sex was the strongest independent predictor, such that female patients were more than twice as likely to complete a combined visit than male patients. These findings replicate studies conducted with patients seen in this clinic (e.g., Fehr et al., 2017), which indicated that initial symptom severity, female sex, and loss of consciousness were predictive of prolonged recovery from concussion. Although outcomes of both studies noted consistent findings with regards to predictors of symptom duration, Fehr and colleagues (2017) primarily explored pre-injury and acute injury characteristics and did not distinguish between patients who presented for an initial visit with sports medicine and those who were ultimately referred for a combined follow-up visit with neuropsychology. As such, the current study expands on Fehr and colleagues' (2017) findings and explores associations with other factors assessed by the CHW concussion clinic and recovery.

This finding is also consistent with a broad literature (e.g., Iverson et al., 2017), suggesting that both pre-injury factors (e.g., patient sex) and acute injury factors (e.g., symptom intensity) influence recovery from concussion, and provides further support for the biopsychosocial model of recovery from mTBI (Conder & Conder, 2015; McCrea et al., 2009; Silverberg & Iverson, 2011). While recovery from mTBI may initially be due to neurobiological injury processes, preinjury factors, psychosocial functioning, coping skills, and the environment interact to determine recovery outcomes.

Collectively, findings from Aim 1 suggest that individuals who were ultimately referred for follow-up visits experienced significantly more symptoms at initial visit, were more likely to have previously experienced a concussion, and were more likely to be female. Results suggest that clinical decision-making about which patients are referred for follow-up visits is consistent with published literature. Further, consistent with previous research, preinjury factors (e.g., female sex and acute injury factors (i.e., initial symptom burden) continue to be important variables to consider related to the prolonged experience of symptoms of concussion.

Another primary objective of this project was to document neuropsychological and emotional functioning, symptom report, and self-reported recovery variables in children and adolescents referred for a combined follow-up visit with neuropsychology. It is important to point out that this sample is a unique subset of children who received specialized treatment for mTBI management. Therefore, results are not reflective of population-based trends, in which many children would receive less specialized care, or would not present to an acute or primary care setting at all.

Consistent with data reported at initial visit, female patients experienced a greater symptom burden than male patients at the combined visit. Review of descriptive statistics indicated that neuropsychological functioning was in the average range across domains. The observation that, on average, neuropsychological scores were within normal limits, is consistent with previous SRC literature suggesting that subtle neuropsychological decrements are observed within the first several days status-post injury and resolve for most individuals within one week (Belanger & Vanderploeg, 2005; McCrea et al., 2003). Although there is less of a consensus in the pediatric literature, a largescale prospective study suggested that the median recovery time for children presenting to the emergency department with mTBI was approximately 29 days (Barlow et al., 2015). On average, individuals in Group 2 were approximately 40 days out from injury, which indicates that they were likely outside of the acute phase and generally not experiencing impairments detectable by neuropsychological testing.

Nonetheless, a primary goal of neuropsychological assessment in the management of mTBI is to detect subtle impairments plausibly associated with injury. A common critique of larger studies, especially meta-analytic techniques, is that presenting large-group analyses potentially obscures the small number of individuals who obtain impaired scores and who may experience significant related distress and functional impairment (Pertab et al., 2009; Rohling et al., 2012). Although scores in this sample were largely within normal limits, rates of obtaining impaired scores ranged from 3.30% to 13.36% across measures, indicating that some individuals in this sample demonstrated impaired performance on neuropsychological measures that may represent a meaningful change from a baseline level of functioning.

In this study, when considering the full sample, the highest rate of impaired scores was observed on the verbal memory delayed recognition aggregated score (13.36%), followed by the verbal immediate memory recall aggregated score (7.58%). While this finding is inconsistent with a body of literature suggesting subtly impaired processing speed in the acute phase of mTBI recovery in athletes (e.g., McCrea et al., 2003), it is consistent with meta-analytic research documenting that clinic-based adult samples exhibit difficulties on measures of delayed memory three months or more after injury (Belanger et al., 2005).

Although the mean estimated pre-morbid intellectual functioning in this sample was in the average range based on a word reading task, approximately 13% of the sample performed in the above average range on this measure. It is possible that, for some individuals in the sample who typically function at a higher level, average or low average neuropsychological performance may reflect subtly diminished cognitive functioning as a result of sustaining concussion. On the other hand, impaired scores on testing may also reflect pre-injury cognitive weaknesses, and/or fluctuations in mood, fatigue, or level of engagement. Given the methodology of the current project, which explored mean-level associations, it is not feasible to consider intra-individual differences in the way that a traditional neuropsychological evaluation would. As such, it is unclear the extent to which scores observed reflect genuine changes in cognitive functioning status-post injury. Nonetheless, pre-injury and acute injury physical, cognitive, and mood functioning remain important considerations to contextualize neuropsychological scores in a clinical setting.

A unique aspect of this project was that performance validity was considered. Overall, the observed rate of PVT failure in this sample (i.e., 8.10%) is consistent with base rate estimates in pediatric samples (e.g., 3-20%; Green et al., 2011; Kirkwood & Kirk, 2010; Kirkwood et al., 2012; MacAllister et al., 2009), but slightly lower than rates of noncredible performance specific to pediatric mTBI patients (e.g., 12-20%; Kirkwood, 2015). It is important to note that performance validity was not systematically and consistently evaluated in this archival sample. The decision about whether to employ standalone PVT measures was based on performance on embedded measures of performance validity (i.e., Reliable Digit Span) and/or clinical judgement related to the credibility of the patient's performance and engagement level. As such, it is likely that the rate of noncredible neuropsychological performance is underestimated.

Despite the relatively small percentage of individuals identified as putting forth suspect performance validity, excluding those individuals' data meaningfully impacted interpretation of broad neuropsychological findings. For example, rates of impaired scores on measures ranged from 3.30% to 13.36% across cognitive constructs when considering the entire sample; however, these rates dropped (0.00 to 8.20%) after excluding participants who failed one or two PVT measures. As neuropsychological measures employed by this clinic are designed to detect subtle cognitive impairments related to mTBI, these findings underscore importance of systematically assessing performance validity in neuropsychological test performance. Impaired scores thought to be related to neurological changes plausibly associated with injury may reflect variability in task engagement.

Performance validity also influenced observed relationships between symptom reporting and neuropsychological performance. When considering the entire sample, significant, small-to-medium negative correlations were observed between symptom burden at initial visit and performance on aggregated measures of trail making, processing speed, working memory, and verbal memory. In contrast, when participants with suspect performance validity were excluded from analyses, significant correlations were only observed between initial symptom reporting and aggregated performance on trail making and working memory measures.

Similarly, performance validity also influenced the predictive relationship between initial symptom burden and neuropsychological performance. When considering all individuals in Group 2, results of a multiple regression analysis containing predictors including initial symptom burden, number of previous concussions, and number of days of school missed suggested that initial symptom burden was the only unique, independent predictor of neuropsychological functioning. In contrast, when individuals with suspect performance validity were removed from analyses, the model was no longer statistically significant. Overall, these findings are similar to those of Araujo and colleagues (2014), who observed that children with suspect performance validity demonstrated impaired neuropsychological performance on measures assessing attention and processing speed, and Kirkwood and colleagues (2014), who observed that performance validity was related to increased symptom endorsement. While these findings could not be directly replicated due to sample size and other methodological issues, the current study highlights the influence of performance validity on both symptom and neuropsychological functioning data.

Given that mTBIs are often associated with affective symptoms, emotional functioning was also considered in this sample. Nearly 24% of individuals who completed anxiety and depression rating scales endorsed a clinically significant level of anxiety and/or depression. This rate is much higher than the base rate of internalizing disorders for children in the United States (Bitsko et al., 2018), although it is consistent with studies that suggest that prolonged recovery from concussion may be related to psychosocial functioning and the experience of concurrent internalizing disorders (Broshek et al., 2015).

Ancillary analyses indicated that children and adolescents who endorsed clinically significant levels of anxiety and/or depression had significantly worse performance on measures of processing speed, verbal fluency, and verbal delayed recognition. Interestingly, removing individuals with suspect performance validity did not significantly alter the pattern of mean differences observed. These findings are consistent with previous research indicating that individuals with depression experience suppressed processing speed performance compared to healthy controls (Elgamal et al., 2010; Gorlyn et al., 2006), and suggest that emotional functioning after injury may contribute to neuropsychological performance above and beyond injury-related factors. As such, findings from the current study indicate that emotional functioning should be considered in the interpretation of neuropsychological test performance.

Collectively, Aim 2 findings underscore the importance of considering performance validity in pediatric mTBI samples. As is the case in all neuropsychological evaluations, proper interpretation of results, inference of brain-behavior relationships, and identification of appropriate recommendations and referrals rely on the assumption that individuals are optimally engaged and forthcoming during the evaluation period. Despite the fact that several studies have documented that a meaningful percentage of children put forth invalid performance on PVTs, pediatric neuropsychologists are comparatively less likely to assess performance validity than their adult counterparts (DeRight & Carone, 2015). Pediatric neuropsychologists may be less likely to routinely assess performance validity under the assumption that children have fewer incentives to engage in performance suppression (Rohling, 2004) or are less sophisticated in their approach to performance suppression, thus being easily detectable by a neuropsychologist (Walker, 2011).

In contrast to these assumptions, simulation studies have suggested that children can realistically feign neurocognitive impairment with minimal coaching (Gunn et al., 2010; Rambo et al., 2015). Additionally, several published case studies have highlighted examples of children engaging in malingering by proxy for secondary gain (e.g., supplemental security income, personal injury litigation; Kirkwood et al., 2010). Perhaps more relevant to this study's population, this body of literature has documented many reasons why children may consciously or unconsciously put forth noncredible performance during neuropsychological evaluation (DeRight & Corone, 2015; Kirkwood et al., 2010). For example, Kirkwood and colleagues (2010) published case examples of children eight years old and older with noncredible performance during mTBI evaluation, whose symptom experience was subtly reinforced by factors including school avoidance, receiving favorable academic accommodations, removal from unwanted sports participation, and management of an undesirable family dynamic. Collectively, there is ample support for consistent and routine use of PVTs in pediatric mTBI assessment.

The final aim of this project was to identify factors that predict the need for extended management of symptoms based on neuropsychological performance and symptom reporting. When considering the full sample, patients completed an average of approximately 9 visits related to concussion, with a range from 1 to 45 visits completed. Unsurprisingly, participants in Group 2 (m = 14.38) completed significantly more follow-up visits compared to those in Group 1 (m = 5.36). Given the lack of published research on rates of service utilization related to management of mTBI, it is unclear whether these numbers are consistent with patients who are seen in other concussion clinics. Jimenez and colleagues (2017) observed, that when corrected for age and sex, patients who sustained an mTBI displayed increased service utilization in the month following concussion compared to pre-injury baseline. On average, patients in their sample completed approximately 4 to 5 visits in the month following their injury. Importantly though, their sample did not distinguish visits whether visits were specifically related to concussion.

While no direct, published comparison exists, results of the current study provide novel information related to service utilization. It is clear that there is a wide range of service utilization that may be associated with significant medical costs in this population. Nonetheless, it is important to point out that service utilization in this sample is unlikely to generalize to the general population of children who sustain mTBIs, as providers in this clinic make appropriate referrals across time points. For example, patients presenting in the CHW Concussion Clinic may be referred for PT services after their initial visit with sports medicine in an attempt to mitigate prolonged recovery from concussion. As such, this sample likely has greater service utilization than the general population, regardless of duration of symptoms. Future research should be conducted to explore rate of service utilization in children who seek medical attention for mTBIs.

This project also attempted to identify predictors of service utilization. Interestingly, symptom burden at initial visit was the only significant, independent predictor of service utilization. Again, although there is limited published research about service utilization in this population, based on Jimenez and colleagues' (2017) findings, it was anticipated that number of pre-injury diagnoses would emerge as a significant predictor of service utilization.

Consistent with Fehr and colleagues (2017) this project highlighted that patient sex is an important consideration in recovery from concussion. Female patients endorsed significantly more symptoms than male patients at initial and combined visits and were twice as likely to be referred for neuropsychological follow up. Further, female sex emerged as a significant predictor of duration between injury and last-follow up visit. Although sex differences in recovery from concussion have been observed frequently in the literature (e.g., see Broshek et al., 2015; Fehr et al., 2017; Iverson et al., 2017), there is debate as to why the discrepancy exists. Some researchers have pointed to physiological differences between male and female patients, including the role of differences in hormonal makeup or physical musculature; however, results of animal models have been mixed with regards to whether female gonadal hormones are protective or iatrogenic in brain injury recovery (e.g., Donders & Woodward, 2003; Roof & Hall, 2000). Other research has suggested that observed sex differences in recovery outcomes may be due to differences in pre-injury somatization level (e.g., Nelson et al., 2016; Root et al., 2016). In particular, Root and colleagues observed that children with higher pre-injury somatization generally reported greater symptom burden, with female participants in the highest quartile of somatization scores reporting significant post-concussive symptoms one month after injury. It is more likely that this finding is related to some combination of physiological differences, personality dimensions, and gender-based social mores related to emotional expression.

Consistent with previous literature (e.g., Fehr et al., 2017; Iverson et al., 2017, Meehan et al., 2014; Yeates et al., 2009), initial symptom burden also emerged as a significant predictor variable of many longer-term outcomes quantified in this project. Although this finding is frequently observed, there does not appear to be a singular, clear explanation for why initial symptom burden predicts recovery outcomes. The relationship is likely complex. Some authors have suggested that, given the nonspecific nature of post concussive symptoms, initial elevations in symptom ratings can reflect a variety of injury-related and non-injury related factors that may contribute to recovery from concussion. For example, Yeates and colleagues (2009), observed that, in some cases, high and persistent post-concussive symptom experience in children was related to more severe injury characteristics (i.e., LOC, GCS < 15, etc.), whereas the experience of moderate and persistent post-concussive symptoms was more likely attributed to characteristics not specific to mTBI. Because many post-concussive symptoms are consistent with a wide variety of commonly-experienced symptoms (e.g., fatigue, headache, etc.), the rating may reflect a myriad of physical complaints that may contribute to functional impairment, regardless of whether symptoms are a result of the injury, itself. For this reason, symptom reporting can be a misleading recovery metric. In both clinical and research domains, it is challenging to disentangle whether these nebulous symptoms are best attributed to mTBI. Nonetheless, given that acute symptom burden is consistently found to be related to recovery outcomes, it is an important clinical and research variable to consider.

Similar to the explanation of sex differences, other researchers have attributed initial symptom burden to pre-injury somatization ratings. For example, Nelson and colleagues (2016) observed that the relationship between pre-injury somatization ratings and symptom recovery ratings was mediated by initial post-concussive symptom ratings. As such, the propensity to be distressed by physical symptoms at baseline may contribute to a more heightened experience of symptoms and/or functional impairment over the course of recovery. It is likely that some combination of these proposed explanations helps to elucidate the current findings.

This research is novel in that it utilized archival clinical data to simultaneously consider the role of pre-injury variables, symptom reporting, and psychosocial functioning variables in a sample of children and adolescents presenting to a multidisciplinary concussion clinic. For patients who received neuropsychological follow-up in this clinic, these variables were considered along with neuropsychological and emotional functioning to better understand recovery from mTBI. Additionally, this is one of the first known studies to document medical service utilization in a sample of individuals who experience protracted recovery form mTBI. Findings from this this project demonstrate the complex and interwoven relationship among factors that influence recovery from mTBI and provide further evidence for the biopsychosocial model of recovery from pediatric mTBI.

Additionally, this study sheds some light on how to improve clinical practice when working with patients who have sustained a mTBI. Consistent with the biopsychosocial model of recovery from concussion (Conder & Conder, 2015; McCrea et al., 2009; Silverberg & Iverson, 2011), it is important to thoroughly consider pre-injury and acute injury factors when determining which patients might be at increased risk for experiencing prolonged recovery from mTBI. Based on the results of this study and others, female sex and symptom burden reported during the acute phase of recovery are important considerations. As such, post-concussive symptoms should be assessed at each encounter. Additionally, emotional functioning should routinely be considered, as emotional functioning may influence neuropsychological performances. The current study also highlights that performance validity is essential to consider when interpreting neuropsychological performance. Consequently, PVTs should routinely be used in the neuropsychological assessment of children who experience mTBI.

Despite the strengths and unique features of this study, there are several limitations that decrease generalizability of findings. For one, the current study does not reflect national demographic characteristics with regards to race and ethnicity. This discrepancy likely reflects racial and ethnic disparities in access to appropriate specialized care (Coker et al., 2010). Further, although the sample aimed to include children ages 8 through 18, the actual ages of children skewed towards older children, limiting the generalizability of these findings to younger children, who are often neglected in the mTBI literature. Although adolescents and young adults sustain mTBI at a higher rate than school-aged children (McCrea, 2008; Zonfrillo et al., 2015), much of the existing literature about recovery from mTBI comes from the young adult SRC population. As such, future research including patients with greater diversity of racial and ethnic background, etiology of injury, and age range, may provide a more complete understanding of how and why individuals recover from mTBI in different ways.

In addition, sample sizes and differences in test administration limited the number and type of analyses that could be appropriately conducted. Because patients completed different types of tests, associated sample sizes were further limited for each measure. As such, composite scores aggregated from measures were derived conceptually rather than empirically. The conceptual aggregation process may have introduced measurement error, ultimately weakening the distinction between different cognitive domains. For example, although some speeded measures, such as Trail Making purport to measure executive functioning, empirical aggregation processes would likely result in a dimension reflecting processing speed and executive functioning, or it is plausible that analyses might highlight that Trails A is more strongly related to pure processing speed tasks than Trails B. Consequently, conceptually aggregated domains are likely less “pure” than empirically aggregated ones (Boone et al., 1998; Demakis, 2006).

Although this is one of the first known studies to consider the role of medical service utilization in recovery from mTBI, researchers were limited to recording visits documented in the electronic medical record only. Although attempts to capture visits that occurred outside of the medical institution were made based on careful review of documentation of outside services, it is possible that other therapeutic visits occurred that were not captured by the current study. As such, the current study may slightly underestimate service utilization associated with mTBI.

Finally, as described above, performance validity was not uniformly or systematically assessed in this sample. As a result, it is possible that this study underestimated the rate of suspect performance validity. Further, recent research has indicated that Reliable Digit Span does adequately discriminate between optimal and suboptimal performance validity in pediatric samples (Vogt, 2018). Reliance on Reliable

Digit Span as an embedded PVT may have suppressed the rate at which suspect performance validity was identified. In addition, despite the fact that self-reported symptoms were an important clinical variable in this study, symptom validity (i.e., the veracity of self-reported symptoms) was not formally assessed. It is critical that future research formally evaluate the potential for response bias by considering both performance and symptom validity in this population.

Given these limitations, future research that simultaneously and more thoroughly considers a number of factors (e.g., acute injury characteristics, pre-injury factors, psychosocial functioning variables, neuropsychological performance, environmental factors, etc.) should be conducted to further shed light on the biopsychosocial model of recovery from concussion. Further, studies should collect prospective data utilizing large samples in order to discriminate among factors. Finally, while symptom report and neuropsychological functioning have been widely explored in existing literature, results of this study suggest that performance and symptom validity should be systematically assessed to elucidate the relationship between symptom reporting and neuropsychological functioning in children and adolescents who experience atypical recovery from concussion.

Conclusions

This study utilized archival clinical data collected at a multidisciplinary concussion clinic to simultaneously consider the role of symptom reporting, neuropsychological and emotional functioning, pre-injury and psychosocial functioning variables, and medical service utilization. Additionally, this is one of the first known studies to document medical service utilization in a sample of children and adolescents who experienced protracted recovery form mTBI. Consistent with a broad literature, female sex and initial symptom burden predicted referral for neuropsychological evaluation. Initial symptom burden also predicted neuropsychological performance and service utilization. A meaningful proportion of the sample reported clinically significant symptoms of anxiety and/or depression, which negatively influenced neuropsychological functioning. Performance validity also emerged as an important consideration in the relationship between symptom report and neuropsychological functioning. When excluding patients with suspect performance validity, the rate at which individuals obtained impaired neuropsychological scores decreased. On average, participants in this sample completed approximately nine medical visits related to their injury, and initial symptom burden predicted increased service utilization. Collectively, these findings provide further support for the biopsychosocial model of recovery from mTBI and underscore the importance of considering symptom reporting and emotional functioning, as well as routinely assessing performance validity in pediatric mTBI samples.

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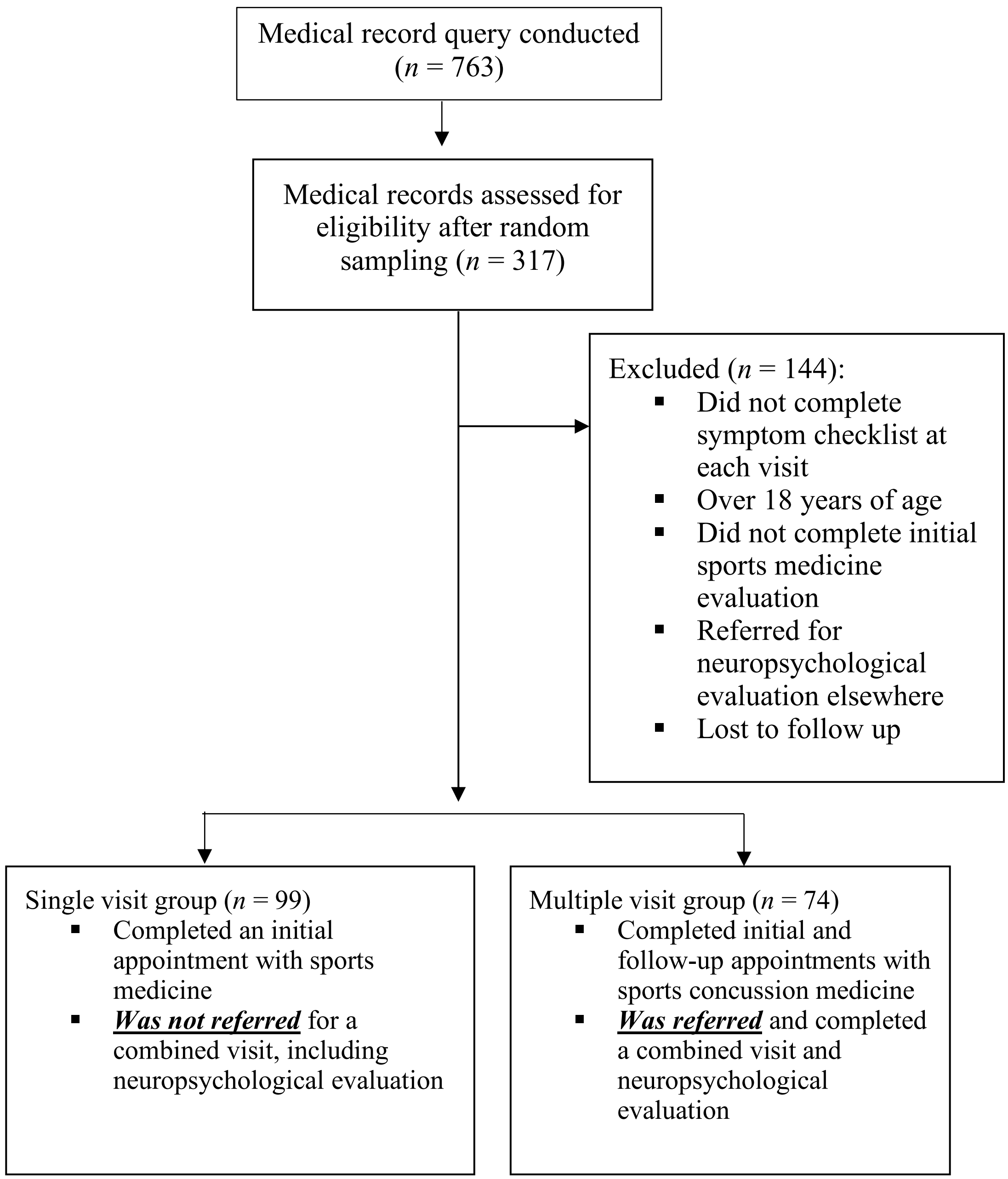
Figure 1.

Study Design



Appendix A

Correlations Among Neuropsychological Variables

Measure	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. WAIS-IV Working Memory Index	-												
2.WAIS-IV Processing Speed Index	.15	-											
3. WISC-V Working Memory Index	-	-	-										
4. WISC-V Processing Speed Index	-	-	. 53**	-									
5. WISC-IV Working Memory Index	-	-	-	-	-								
6. WISC-IV Processing Speed Index	-	-	-	-	.28	-							
7. Trail Making Part A	-.20	.40	.72	.23	-.81	.13	-						
8. Trail Making Part B	-.04	.82*	.59	.41	.38	.63	.36	-					

Measure	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
9. D-KEFS Trail Making Trial 1	-.19	.38	.38*	.55**	.57	.51	-	-	-				
10. D-KEFS Trail Making Trial 2	-.20	.47	.44*	.46*	.62	.47	-	-	.74**	-			
11. D-KEFS Trail Making Trial 3	-.13	.51	.46*	.55**	.51	.34	-	-	.70**	.76**	-		
12. D-KEFS Trail Making Trial 4	.06	.60*	.26	.24	.57	.49	-	-	.40**	.63**	.66**	-	
13. D-KEFS Trail Making Trial 5	-.42	.35	.48*	.51**	.51	.43	-	-	.69**	.81**	.83**	.66*	-
14. D-KEFS Verbal Fluency: Letter Fluency	.51*	.07	.36	.34	-.01	-.02	-.56	-.34	-.01	.24	.37*	.33*	.34*
15. D-KEFS Verbal Fluency: Category Fluency	.50*	-.15	.40*	.69**	.25	.47	-.59	-.35	.33*	.25	.25	.06	.17
16. D-KEFS Verbal Fluency: Category Switching	.15	.16	.25	.56**	.08	-.03	-.42	-.01	.28	.30*	.43**	.30*	.31
17. D-KEFS Verbal Fluency: Switching Accuracy	.21	.09	.29	.51**	.15	-.11	-.45	-.03	.31*	.34*	.47**	.35*	.34*
18. WRAML-2 Verbal Learning Immediate Recall	-	-	.16	.78**	.23	.01	.30	.65	.25	.30	.27	.15	.23

Measure	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
19. WRAML-2 Verbal learning Delayed Recall	-	-	.14	.46*	.41	.16	.49	.61	.16	.27	.18	-.04	.09
20. WRAML-2 Verbal Learning Delayed Recognition	-	-	.36	.57**	-.12	.77	.03	.29	.24	.27	.22	-.04	.10
21. HVLT-R Total Recall	.25	.41	.77*	.66	.65	.34	.24	.06	.32	.18	.22	.48*	.04
22. HVLT-R Delayed Recall	.02	.30	.80*	.75*	.44	.36	.39	-.26	.08	.20	.22	.39	.01
23. HVLT-R Delayed Recognition	.57**	.39	.77*	.82*	.39	.32	.24	-.21	.47*	.47*	.44*	.42*	.26
24. BVMT-R Total Recall	.48	.02	.88**	.89**	.99	.77	-	-	.46	.51*	.43	.60*	.23
25. BVMT-R Delayed Recall	.28	.33	.81*	.75	.57	.99	-	-	.87**	.74**	.64**	.55*	.51*

Note. *indicates statistically significant Pearson correlation, $p < .05$, ** indicates $p < .01$.

Measure	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.
14. D-KEFS Verbal Fluency: Letter Fluency	-											
15. D-KEFS Verbal Fluency: Category Fluency	.39**	-										
16. D-KEFS Verbal Fluency: Category Switching	.44**	.49**	-									
17. 17. D-KEFS Verbal Fluency: Switching Accuracy	.41**	.43**	.93**	-								
18. WRAML-2 Verbal Learning Immediate Recall	.30	.49*	.51**	.47*	-							
19. WRAML-2 Verbal learning Delayed Recall	.29	.48**	.39	.40*	.79**	-						
20. WRAML-2 Verbal Learning Delayed Recognition	.16	.39	.14	.21	.71**	.64**	-					
21. HVLT-R Total Recall	.17	.37*	.42*	.42*	-	-	-	-				
22. HVLT-R Delayed Recall	.17	.43*	.24	.19	-	-	-	.75**	-			
23. HVLT-R Delayed Recognition	.19	.49**	.25	.20	-	-	-	.55**	.65**	-		
24. BVMT-R Total Recall	.30	.58*	.56*	.57*	-	-	-	.65**	.61**	.56*	-	

Measure	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.
25. BVMT-R Delayed Recall	.22.	.63**	.50*	.36	-	-	-	.62**	.73**	.60**	.56*	-

Note. *indicates statistically significant Pearson correlation, $p < .05$, ** indicates $p < .01$.