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Concussion History and Behavioural Problems in Child and Adolescent Athletes

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Concussion History and Behavioural Problems in Child and Adolescent Athletes

By

Robin Richardson

A Thesis
Submitted to the Faculty of Graduate Studies
through the Department of Psychology
in Partial Fulfillment of the Requirements for
the Degree of Master of Arts
at the University of Windsor

Windsor, Ontario, Canada

2018

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Concussion History and Behavioural Problems in Child and Adolescent Athletes

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September 18, 2018

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ABSTRACT

Sport-related concussion has become a “hot-button” topic in the media and in science. Increasingly, researchers are beginning to understand the association between concussion history and psychosocial adjustment in adults. But little research has been conducted examining this relation in children, and studies done have yielded discrepant results. Therefore, the present study aimed to investigate this relation by using current internalizing and externalizing behaviour to predict past history of concussion among child athletes. Forty-eight (77.1% female) elite community athletes aged 11 to 14 years old (*M* age = 12.95) completed baseline assessments at the University of Windsor as part of a larger concussion management protocol. Psychosocial functioning was assessed using the parent-report version of the Behavior Assessment System for Children (BASC-3; Internalizing and Externalizing scales only), and previous concussion history was assessed via a demographics questionnaire. A binary logistic regression analysis using the BASC-3 scales as predictors and concussion history (0 vs. ≥ 1 previous concussion) as the dichotomous outcome variable indicated that the predictors were unable to differentiate between athletes with and without a prior history of concussion. Moreover, neither predictor significantly contributed to the model. These findings suggest that there is no relation between concussion history and current behavioural functioning in this population. Implications of these findings are discussed given the methodological and statistical limitations of the study. Future research should seek to replicate this methodology with more diverse samples to ensure greater generalizability of results.

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LIST OF ABBREVIATIONS

ADHD	Attention-Deficit Hyperactivity Disorder
AUC	Area Under the Curve
BASC-3	Behaviour Assessment System for Children – 3 rd Edition
BDI	Beck Depression Inventory
BRIEF	Behaviour Rating Inventory of Executive Functioning
CBCL	Child Behavior Checklist
CESD	Centre for Epidemiological Studies Depression
GPA	Grade Point Average
HADS	Hospital Anxiety and Depression Scale
ImPACT	Immediate Post Concussion Assessment and Cognitive Testing
MLR	Multinomial Logistic Regression
NFL	National Football League
PCSS	Post Concussion Symptom Scale
PRS	Parent Rating Scale
ROC	Receiver Operating Characteristic
SIS	Second-Impact Syndrome
SRCC	Sport-Related Concussion Centre
TBI	Traumatic Brain Injury

CHAPTER 1.

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Child and adolescent sport-related concussion research is still in its infancy, but there is ample literature showing objectively that mild hits to the head can cause concussion and can have long-term consequences (Guskiewicz & Mihalik, 2011). “Shake it off and get back out there!” is a phrase often heard by parents and players alike following an injury on the field. Unfortunately, this “shake it off” mindset permeates today’s athletic culture and encourages children to continue to play following a hit to the head, potentially increasing their risk for future concussive injuries (Kroshus, Baugh, Stein, Austin, & Calzo, 2017; Kroshus, Garnett, Baugh, & Calzo, 2016).

Increasingly, researchers are studying the long-term behavioural consequences of sport-related concussion in adults. Results have shown that worse behavioural outcomes are associated with more previous concussions (e.g., Guskiewicz et al., 2007; Didehbani, Munro Cullum, Mansinghani, Conover, & Hart, 2013). It is still unclear, however, how concussions affect behavioural and emotional variables, such as internalizing and externalizing behaviours, in children and adolescents. Few studies to date have examined the relationship between concussion frequency and psychological adjustment, and these studies have yielded discrepant results (Liu & Li, 2013; Plourde, Yeates, & Brooks, 2018). Furthermore, sex differences have not been examined with respect to the association between concussion history and behavioural problems among children and adolescents. Because there are more male than female athletes, most concussion research has been carried out on males, but it is unclear whether these results can be generalized to

females. Therefore, the present study will have the unique aim of investigating how previous sport-related concussions relate to baseline internalizing and externalizing behaviour among children and adolescents, and how this association might differ between males and females.

To gain a thorough understanding of the relationship between behaviour and concussion, and given the evolving conception of concussion, it is first important to define what is currently meant by “concussion.” This will be followed by a discussion of the sport-related concussion literature as it relates to children, and how children may be uniquely at risk for more severe recovery compared to adults. A review of the outcomes of multiple sport-related concussions will aim to illustrate how the effects of multiple concussions may be cumulative, and consideration will be given to the association between concussion frequency and internalizing and externalizing behaviour. Finally, the goals of the present study and accompanying hypotheses will be discussed in detail.

1.2 Definition of Concussion

A consensus statement from the 2016 International Conference on Concussion in Sport defined concussion as a traumatic brain injury (TBI) induced by biomechanical forces (McCrory et al., 2017). The biomechanical forces that cause concussion include the application of linear and/or rotational forces to the brain, although there is no biomedical threshold for a clinical diagnosis of concussion (Guskiewicz & Mihalik, 2011; Halstead, Walter, Council on Sports, & Fitness, 2010). Linear forces result from a hit to the head’s centre of gravity (Guskiewicz & Mihalik, 2006), whereas rotational forces result from an off-centre hit, causing the head to accelerate on an arc around its centre of gravity (Guskiewicz & Mihalik, 2006). This motion can generate forces causing

tissue deformation in the brain such as shearing of axons (Barth, Freeman, Broshek, & Varney, 2001; Meaney & Smith, 2011). Biomechanical forces can result from a direct hit to the head, neck, face, from inertial forces caused by a hit elsewhere on the body, or from a fall causing the head to strike a surface such as the ground (McCrory et al., 2013). Concussive injury typically leads to rapid onset of impairment in neurological function, which is usually short-lived (7–10 days) and resolves spontaneously (McCrory et al., 2017)

The sequelae of concussion are highly heterogeneous. Although the most commonly reported symptom among adults is headache, followed by dizziness, and then confusion (Guskiewicz et al., 2007; Guskiewicz et al., 2003; Guskiewicz, Weaver, Padua, & Garrett, 2000), many other symptoms have been reported following concussive injury, including affective symptoms and changes in sleep habits (McCrory et al., 2017). There is also evidence to suggest that certain symptoms may differ by sex; for example, Frommer and colleagues (2011) found that females tended to report more somatic and neurological symptoms (e.g., drowsiness, sensitivity to noise) whereas males tended to report more cognitive symptoms (e.g., amnesia, confusion/disorientation).

In addition to symptom heterogeneity, concussions can also vary in severity. Although initial grading scales developed for assessing concussion used ‘alteration of consciousness’ as an index of severity, studies have demonstrated that loss of consciousness occurs in only about 10% of concussions (Guskiewicz et al., 2003; Guskiewicz et al., 2000; Harmon et al., 2013; Karlin, 2011). The summary statement of the First International Symposium on Concussion in Sport recommends abandoning

injury grading scales altogether in favour of measures that assess recovery time as an indicator of concussion severity (McCrory et al., 2005).

1.3 Sport-Related Concussion

The Centres for Disease Control and Prevention estimates that between 1.6 and 3.8 million sport-related concussions occur annually in the United States (Langlois, Rutland-Brown, & Wald, 2006). In a 2002 study of Canadian university athletes, over two-thirds of football players and slightly less than two thirds of soccer players reported experiencing symptoms consistent with concussion following a hit to the head in the previous year (Delaney, Lacroix, Leclerc, & Johnston, 2002). Additionally, among 85% of football players and 82% of soccer players, the reported injury was not their first concussion, indicating that multiple concussions are common in athletes (Delaney et al., 2002). Studies investigating sex differences in concussion incidence among collegiate athletes have found that females not only have a greater rate of concussion than males, but that females are also more likely to experience more severe and prolonged outcomes (Broshek et al., 2005; Covassin, Swanik, & Sachs, 2003). Although concussion research in collegiate and other adult populations is relatively well-established, there is a paucity of empirical findings specific to sport-related concussion in children, particularly with regard to sex differences (McCrory et al., 2017). The remaining literature review will focus on research regarding childhood sport-related concussions and associated sex differences.

1.4 Childhood Sport-Related Concussions

Children¹ participate in organized sports more often than adults; consequently, child athletes sustain the majority of concussions (Halstead et al., 2010). Concussions obtained through sport tend to be more frequent and more severe than concussions obtained through other leisure activities; for example, a 10-year study of emergency room visits for concussion among children aged 8 to 19 years found that approximately half of all observed concussions in that age group were sport-related (Bakhos, Lockhart, Myers, & Linakis, 2010; Browne & Lam, 2006). Further, by the start of high school, 53% of student athletes have reported at least one concussion (M. Field, Collins, Lovell, & Maroon, 2003). Additionally, incidence of childhood sport-related concussion appears to be on the rise (Lincoln et al., 2011), although this may be in part due to greater injury awareness and legislation (Kerrigan & Giza, 2017). Symptom patterns also appear to differ between adults and children. The most common post-concussive symptoms reported by adults are headache, dizziness, and confusion, whereas the most common symptoms reported by children are headache, fatigue, and feeling slowed down (Gioia, Collins, & Isquith, 2008; Guskiewicz et al., 2000).

Because the developing brain is presumed to have greater neuroplasticity than the mature brain, researchers initially believed that children had a greater chance of recovery following TBI compared to adults (Mundkur, 2005), but the current literature suggests otherwise. The developing brain appears to be more susceptible to diffuse injury or injury over a widespread area of the brain (Daneshvar et al., 2011). Due to the shortage of age-

¹ Going forward, the term “children” shall refer to all individuals 18 years or younger.

specific research on the consequences of concussion in youth, concussions in children are often managed using guidelines designed for collegiate or adult populations (McCrary, Collie, Anderson, & Davis, 2004). The current literature, however, demonstrates marked anatomical and biomechanical differences between child and adult athletes that may leave children more susceptible to head injury and place them at greater risk for prolonged recovery following concussion (M. Field et al., 2003; Gioia, Schneider, Vaughan, & Isquith, 2009).

1.4.1. Elevated concussion risk among child athletes. There are anatomical and biomechanical differences between the developing brain and the adult brain that may also contribute to the differences found in concussion between children and adults. The head to body size ratio, neck strength, and brain water content, to name a few, differ between children and adults and may contribute to some of the age-specific severity and recovery trajectories seen in children following concussion (Guskiewicz & Valovich McLeod, 2011; Meehan, Taylor, & Proctor, 2011; Viano, Casson, & Pellman, 2007). These anatomical differences may also partially account for the increased incidence of concussions in females, as they are generally smaller and have weaker necks than males (Covassin et al., 2003).

1.4.2. Recovery from concussion among child athletes. Research has also shown differences between children and adults in recovery from concussion. A 2015 meta-analysis examined six published studies investigating recovery duration of post-concussive symptoms in high school and collegiate athletes (Williams, Puetz, Giza, & Broglio, 2015). The results indicated that, based on a post-concussion symptom scale, recovery was achieved in 15 days among high school athletes, compared to only 6 days

among collegiate athletes (Williams et al., 2015). Differences in recovery based on neurocognitive testing showed a much smaller gap between the two age groups, with an average recovery of 7 days for high school athletes compared to 5 days for collegiate athletes (Williams et al., 2015).

Considering the cognitive dimension further, several researchers have found that high school athletes, compared to collegiate athletes, showed a longer duration of memory impairment relative to non-concussed, age-matched controls (M. Field et al., 2003; Sim, Terryberry-Spohr, & Wilson, 2008). Similar research has found that high school athletes showed poorer performance in visual and verbal memory 7 days after concussion compared to college athletes (Covassin & Bay, 2012). These findings suggest that younger age may in fact be associated with longer recovery duration following concussive injury.

Another study involved parent reporting of post-concussive symptoms following either a concussion or orthopedic injury in their child (Taylor et al., 2010). Across both types of injury, the results indicated that number of reported post-concussive symptoms was related to age: parents of younger children reported a greater number of symptoms than parents of older children (Taylor et al., 2010). This suggests that the relationship between age and post-concussive symptoms exists independent of the factors associated with the concussion itself.

Sex differences in symptom recovery. Age has also been shown to interact with sex in terms of concussion outcome and recovery. A 2017 study compared post-concussive symptom reports between males and females and found that, among participants 14–19 years old, females reported both greater symptom severity as well as a

greater total number of post-concussive symptoms (Tanveer, Zecavati, Delasobera, & Oyegbile, 2017). Conversely, among participants 10–13 years old, there were no sex differences, indicating that age may moderate sex differences in symptom reporting following concussion. Similar findings were discovered in a study investigating post-injury symptom reporting following mild TBI (Preiss-Farzanegan, Chapman, Wong, Wu, & Bazarian, 2009). Results indicated that, among adults, females were at greater odds of having elevated Rivermead Post Concussion Symptoms Questionnaire (N. S. King, Crawford, Wenden, Moss, & Wade, 1995) scores when compared to males, but this difference was not seen among minors, further suggesting that sex differences in post-injury symptom reporting may depend on age.

1.5 Multiple Concussions

Another important moderator of concussion outcome in children is whether there is a history of prior concussions. Due to the high incidence of concussions in organized sports, multiple concussions are not uncommon and can have detrimental consequences on the athlete. At present, most research on repeat concussions has focused on adult populations. Few of these studies included female athletes, and those that did failed to analyze or report sex differences, leaving much to be learned about sex differences following repeat concussion.

1.5.1 Recurrent concussions in adulthood. Among adults, multiple concussions appear to be accompanied by more severe symptoms and a slower recovery than a singular concussion (Covassin, Moran, & Wilhelm, 2013; Guskiewicz et al., 2005; Guskiewicz et al., 2003). Athletes with a history of multiple concussions have been found to report more symptoms at baseline and are more likely to experience significant

memory problems after a subsequent concussion compared to athletes without history of multiple concussions (Iverson, Gaetz, Lovell, & Collins, 2004). Athletes with three or more concussions have also been found to take longer to recover compared to athletes with only one previous concussion, based on their neurocognitive performance and reported symptoms, suggesting a cumulative effect (Covassin et al., 2013). Additionally, studies using event-related potentials have shown differences in electrophysiological activity of the brain between athletes with multiple concussions compared to athletes with a singular concussion, even after post-concussive symptoms had abated (Elleberg, Henry, Macciocchi, Guskiewicz, & Broglio, 2009). This indicates that multiple concussions may cause persistent neural differences.

Consecutive concussions can be especially problematic when the athlete has not yet healed from the primary concussion. The current recommendation for concussion management is to immediately remove the player from the game, and then follow a graduated six-step 'return-to-play protocol' before being allowed to fully re-engage in the sport (McCrory et al., 2017). Excessive physical or cognitive activity before full recovery may exacerbate symptoms and prolong recovery (Asken et al., 2016; McCrory et al., 2009), but excessive rest or inactivity is also linked to poorer outcomes (Silverberg & Iverson, 2013). Therefore, the primary purpose of the six-step program is to encourage return-to-play in a graduated manner, thus facilitating optimal recovery.

The return-to-play protocol is also aimed at helping the athlete avoid further injuries before the brain has fully healed from the initial concussion. A second impact before the brain has fully healed from the first impact may lead to prolonged symptom duration and neurocognitive recovery, as well as deficits in cognitive ability and reaction

time, which could increase susceptibility to further concussions (Longhi et al., 2005). A second impact may be particularly harmful if the brain has not fully recovered because of the cellular processes underlying concussion. Following a brain injury, a “neurometabolic cascade” takes place, which involves a cascade of ionic, metabolic, and pathophysiological events accompanied by axonal injury (Giza & Hovda, 2014). The decreased cerebral blood flow and mitochondrial dysfunction that accompany this neurometabolic cascade leave the athlete highly vulnerable to further injury (Giza & Hovda, 2014). Indeed, studies have demonstrated that a second injury occurring before the brain has had a chance to fully heal can result in worsening cellular metabolic changes and more pronounced cognitive deficits (Giza & Hovda, 2014). In fact, it has been proposed that any athlete who sustains three or more concussions in the same season either be removed from the sport for a prolonged period of time or retire (Halstead et al., 2010).

Risk factors for multiple concussions among adults. The greatest risk factor for multiple concussions among adults may be a concussion itself. Results of multiple studies have shown that a history of concussion is associated with a 2 to 5.8 times higher risk of sustaining another concussion (Delaney et al., 2002; Guskiewicz et al., 2007).

Additionally, a dose-response relationship has been shown between number of previous concussions and risk of incident among collegiate football players, even after controlling for factors such as division of play, playing position, number of years playing, academic year in school, and BMI (Guskiewicz et al., 2003).

1.5.2 Recurrent concussions in childhood. As most of the research on recurrent concussions has been conducted on adults, multiple concussions in childhood remain

poorly understood. This section will review the literature on outcomes of recurrent concussion in childhood, including outcomes relating to cognitive recovery and symptom recovery. Risk factors for multiple concussions among children will also be reviewed.

Halstead, Walter, and the Council on Sports Medicine and Fitness (2010) note that the effects of multiple concussions on the developing brain appear to be cumulative, indicating that outcomes may worsen with each successive concussion. For example, one study found that asymptomatic high school athletes with a history of two or more concussions more than half a year prior to neuropsychological testing performed similarly to athletes who had sustained a concussion the prior week (Moser, Schatz, & Jordan, 2005). The same study also found a lower academic GPA among students with multiple concussions. The authors made no report of the athletes' sex.

In contrast, a study published in 2018 in the *Journal of Neurology* found no difference in immediate post-concussive cognitive function between children with one or more previous concussions compared to children for whom this was their first concussion, suggesting that recurrent concussions do not have a cumulative effect on cognition (Oyegbile, Delasobera, & Zecavati, 2018). Individuals with a previous concussion history did, however, report more post-concussive symptoms after their present injury compared to individuals suffering from their first concussion.

Similarly, another study of long-term outcomes of childhood concussion found no effect of number of previous concussions on current cognitive functioning among male high school students, but a positive association was found between number of previous concussions and current baseline concussion-related symptoms (Brooks, Mannix, et al., 2016). The authors speculate that multiple previous concussions may be associated with

underlying changes in neural physiology that contribute to these lingering symptoms. Additionally, in a 2015 study of nearly 32,000 American high school athletes, results indicated that history of multiple concussions is a significant predictor of baseline post-concussive symptoms, although it was found to be a stronger predictor among females than among males (Iverson et al., 2015).

A few studies have investigated the relationship between concussion history and symptom recovery following a subsequent concussion with conflicting findings. Miller and colleagues (2016) examined children at a pediatric concussion clinic and found that a history of previous concussion was associated with a 3.67 times greater chance of having post-concussive symptoms lasting longer than 28 days. Howell and colleagues (2016), however, found that a history of multiple concussions was not a significant predictor of being symptomatic 28-days post-injury.

It is unclear why there is a discrepancy between the findings of Miller and Howell. Both studies had similar age ranges (4-to-18-year-olds for Miller's study and 6-to-18-year-olds for Howell's study) and were conducted at community concussion clinics. Howell and colleagues explicitly stated the inclusion of covariates in their logistic regression model, including age, sex, Post-Concussion Symptom Scale (Lovell, Collins, Podell, Powell, & Maroon, 2000) scores (somatic, vestibular-ocular, cognitive, sleep, and emotional symptoms), loss of consciousness at time of injury, amnesia at time of injury, prior treatment for headaches, prior treatment for migraines, or family history of concussion, whereas Miller and colleagues did not explicitly state the included covariates. It may be that the difference lies in the adjustment of the model. Notably, the results of Howell's study do not necessarily indicate an absence of association between

multiple concussions and symptom recovery; individuals with multiple concussions may have taken longer to recover than those with one concussion, but they still recovered before 28 days, and thus their recovery was not defined as “prolonged” by this model. Future studies should seek to clarify whether there is a relationship between recurrent concussions and prolonged symptom recovery following concussive injury.

One particularly worrisome situation of repeat concussion is known as Second-Impact Syndrome (SIS). In SIS, a second head injury is sustained before the first has fully healed. SIS involves a loss of autoregulation of cerebral blood flow, which leads to vascular congestion, swelling of the brain, and increased intracranial pressure (Karlin, 2011). Within minutes of being hit, brain herniation, coma, and death can occur. All reported cases of SIS have occurred in athletes 19 years of age or younger (Guskiewicz & Valovich McLeod, 2011; Halstead et al., 2010). Additionally, since 1945, over 75% of head injury-related fatalities from playing sports recorded by the National Centre for Catastrophic Sports Injury Research occurred in athletes of high school age or younger (Boden, Tacchetti, Cantu, Knowles, & Mueller, 2007; Cantu & Mueller, 2003).

It is unclear why a developing brain is at a disproportionately high risk for this catastrophic event, although one reason may be the neurometabolic differences between adults and children. Some of the pathophysiological disruptions to the brain that take place following the primary head injury are even more pronounced in children than in adults; in particular, the developing brain has been shown to have higher levels of glutamate sensitivity, which contributes to the metabolic cascade (McDonald & Johnston, 1990; Meehan et al., 2011). These neurometabolic differences may make children more susceptible to catastrophic consequences of repeat concussion before full recovery.

Risk factors for multiple concussions among children. In one of the first studies to examine risk factors for multiple concussions in high school athletes, Guskiewicz and colleagues (2000) found that high school football players who experience a concussion are almost three times more likely to experience a second concussion during the same season compared to players who have no history of concussion. This indicates that, similar to adults, sustaining a concussion increases the risk of future concussions among children. As this study did not report demographics, it is unknown whether sex differences were found, or whether female athletes were included.

In summary, the literature yields conflicting results regarding the association between concussion frequency, cognition, and post-concussive symptoms. Some have found poorer cognitive performance among athletes with multiple previous concussions, whereas others have found no such effect. It is also unclear whether there is an association between previous concussion frequency and baseline post-concussive symptoms, or whether concussion history is related to length of recovery. Additionally, a history of multiple concussions may put one at a higher risk of future concussions. Given that so few studies included female participants, it is unknown at this time whether there are sex differences regarding the risks and consequences of multiple concussions in children. In contrast to the relative wealth of studies investigating the associations between concussions and cognition, symptom recovery, and risk of future concussion, few studies have investigated the association between concussions and behavioural change.

1.6 Concussion and Behavioural Disturbances

Behavioural change following concussion is common, and according to the summary statement from the Fifth International Conference on Concussion in Sport, the suspected diagnosis of concussion can be made based on behavioural change alone (McCrory et al., 2013; McCrory et al., 2017). Increased levels of depressive, anxious, and aggressive behaviour have been shown to occur following concussive injury, but it has also been suggested that premorbid levels of certain behavioural traits, such as impulsivity and aggression, may increase susceptibility to concussion (Guskiewicz et al., 2007; Kerr et al., 2014; Moore, Terryberry-Spohr, & Hope, 2006). Furthermore, premorbid depressive symptoms may increase the likelihood of experiencing depressive and anxiety symptoms post-concussion (Yang, Peek-Asa, Covassin, & Torner, 2015), and may prolong post-concussive symptom recovery (Morgan et al., 2015). Clearly, the relationship between concussion and behavioural change is complex. Although the nuances of this association will be detailed further in the following sections, few researchers have focused their attention on children, and thus most of the reviewed studies are specific to adults.

1.6.1 Internalizing behaviours. Internalizing behaviour refers to behaviour and emotions characterized by negative mood states and inhibition, such as depressive- and anxiety-like symptoms (S. M. King, Iacono, & McGue, 2004). Depressive- and anxiety-like symptoms often occur together and likely share underlying functional neuroanatomy (Moore et al., 2006). Integrative models for the pathophysiology of depressive and anxiety disorders involving fronto-limbic neural circuitry have received support; brain centres involved in this circuitry include the frontal lobes, the hippocampus, and the

amygdala (Cullen, Klimes-Dougan, Kumra, & Schulz, 2009; Moore et al., 2006). Similarly, brain regions commonly disrupted in concussion include the medial temporal lobes, which house the hippocampus and the amygdala, and the frontal lobes (Bigler, 2008; Bryant, 2008). Disruption to these systems caused by TBI may impair one's capacity to regulate emotions, contributing to post-concussive internalizing behaviours (Bryant, 2008). Given this high degree of overlap between brain regions commonly disrupted in concussion and brain regions implicated in internalizing behaviours, it is likely that there is an association between the neurological disruption caused by the concussion and the resulting internalizing behaviours.

Research has demonstrated a strong association between concussion and internalizing behaviour, with depression as a frequently-cited cited long- and short-term psychological disturbance after TBI; further, post-injury depression has been associated with prolonged recovery from concussive injury (Guskiewicz et al., 2007; Mooney, Speed, & Sheppard, 2005). Among retired male National Football League (NFL) athletes, a higher incidence of clinical depression (diagnosed during or after the player's football career) was found in athletes who had a concussive history compared to those who did not (Guskiewicz et al., 2007). Additionally, a linear relationship was found between number of previous concussions and percentage of players that had received clinical diagnoses of depression. After controlling for factors such as age, number of years since retirement, number of years played, level of cognitive impairment, physical health, and medical status, it was found that retirees with three or more previous concussions were still 2.6 times more likely to have received a diagnosis of depression, and retirees with one or two concussions were 1.4 times more likely to have received a diagnosis of

depression, compared to retirees with zero concussions (Guskiewicz et al., 2007). Similar results were found between number of previous concussions and current depressive symptoms including sadness, nervousness, or feelings of stress (Guskiewicz et al., 2007), indicating that the linear trend between concussion history and depression does not only pertain to lifetime clinical diagnoses of depression, but also to current depressive-like symptoms.

A follow-up study of this same population nine years later reported previous concussions stratified into five categories: 0, 1 to 2, 3 to 4, 5 to 9, and 10+ previous concussions (Kerr, Marshall, Harding, & Guskiewicz, 2012). A strong dose-response relationship between number of previous concussions and risk of depression diagnosis was found after controlling for multiple covariates, including physical health. The risk for a depression diagnosis ranged from 3% in the “0 previous concussions” group to 27% in the “10+ previous concussions” group. Additionally, excluding participants who had already received a depression diagnosis prior to sustaining their first concussion, results indicated that 10.2% of retirees reported a new diagnosis of depression since responding to the previous survey nine years earlier.

A similar study of retired male NFL players utilized a non-concussed non-athlete control group for comparison (Didehbani et al., 2013). The number of previous concussions among the NFL athletes ranged from 1 to 11, with an average of 4 concussions. Compared to the control group, the NFL athletes scored significantly higher on all factors (affective, cognitive, and somatic) of the Beck Depression Inventory (BDI; Beck, 1988), with higher scores indicating more depressive symptoms. Additionally, a

positive correlation was found between number of previous concussions and total score on the BDI among the NFL players.

Fewer studies have looked specifically at anxiety-like behaviours following concussion. A review article by Moore and colleagues (2006) examining anxiety sequelae of mild TBI found large inconsistencies in prevalence rates of anxiety disorders across the studies examined, but noted that, overall, prevalence rates in post-injury groups appeared to be markedly higher than that of the general population. Additionally, the authors suggested that rates of comorbidity between depressive and anxiety disorders among those with mild TBI may be higher than the rates of comorbidity in the general population, which is likely owing to the overlap in functional neuroanatomy between depressive and anxious behaviours and concussion.

Given that depressive- and anxiety-like behaviours commonly co-occur following concussion, many studies examine both types of behaviours following concussive injury. For example, a study of retired male Filipino boxers found a linear relationship between number of knockouts the boxer had experienced and Hospital Anxiety and Depression Scale scores (HADS; Zigmond & Snaith, 1983), where higher scores are indicative of more depressive and anxious behaviour (Chiarini et al., 2013). However, the depression and anxiety subscales of the HADS were not analyzed independent of one another, so it is unclear whether the increase in total overall symptoms was mostly accounted for by the relationship between depressive behaviour and head injury, as seen in previously cited literature.

A qualitative study by Caron and colleagues (2013) sought to describe the experiences of five former male National Hockey League players who had multiple

concussions. All players interviewed had to retire early due to concussive injury. In their statements, two players described anxious feelings and paranoia that persisted for many years following their concussions. With regards to anxiety, one player described the year following his last concussion as, “the worst [he’d] ever felt,” and another described it as, “feeling like [he] was losing [his] mind.” The players reported that one contributor to their anxiety was the feeling that no one understood the “invisible injury” they were facing. All players also noted depressive symptoms following their concussions, and three of the five players contemplated suicide. However, it is unclear whether these symptoms were due to pathophysiological causes or psychosocial and adjustment factors. Regardless, the players clearly experienced suffering that was either directly or indirectly due to sustaining multiple concussions.

In summary, there appears to be a strong association between concussion and internalizing behaviours in adulthood. This may be due in part to the overlap in functional neuroanatomy between concussion and internalizing behaviours, but this association may also be caused by psychosocial and adjustment factors following head injury. Unfortunately, many of the previous studies were conducted only on males, and thus it is unclear whether the findings generalize to females. Only one study to date has investigated symptoms of both depression and anxiety following concussion in male and female collegiate athletes (Yang et al., 2015). In this study, emotional and behavioural symptoms of depression and anxiety were assessed at baseline and post-injury using the Center for Epidemiological Studies Depression Scale (CESD; Radloff, 1977). Of the 71 athletes who sustained concussions across all genders, approximately one-fifth reported experiencing symptoms of depression post-injury, one-third reported experiencing

symptoms of anxiety, and 14% reported symptoms of both depression and anxiety (Yang et al., 2015). Concussed athletes who reported symptoms of depression at baseline were over 4.5 times more likely to experience depressive symptoms post-injury and almost 3.5 times more likely to experience symptoms of anxiety following their concussion compared to athletes who had no symptoms of depression at baseline. Conversely, pre-injury symptoms of anxiety did not increase the likelihood of experiencing post-injury symptoms of anxiety or depression. These findings suggest that pre-injury depressive symptoms may be a vulnerability factor for post-injury internalizing symptomatology in athletes. Interestingly, sex differences were not found in post-concussive depressive or anxious symptoms, suggesting that the mechanisms causing these post-injury symptoms may not differ between males and females.

Concussion and internalizing behaviours in children. Fewer studies have investigated the relationship between internalizing behaviours and concussions in children. One study by Liu and Li (2013) investigated the relationship between head injury and behavioural outcomes in a cohort of 6-year-old Chinese children. Parents reported their child's history of head injury and completed the Chinese version of the Child Behaviour Checklist (CBCL; Achenbach, 1999), a rating scale widely used for assessing behavioural and emotional problems in children. Parent ratings on the CBCL are converted to standardized *T*-scores, whereby higher scores are indicative of more behavioural problems. Children were stratified into groups consisting of no head injury, single mild head injury, and multiple mild head injuries, where mild head injury was defined as no loss of consciousness and no hospitalization for treatment due to injury. Results indicated that standardized *T*-scores from the CBCL increased steadily with the

frequency of mild head injury across both the internalizing and externalizing clinical subscales. Compared to children with no head injury, children with just one head injury demonstrated significantly greater *T*-scores on the Withdrawal subscale, one of the scales contributing to the Internalizing Behaviours Composite. Mild head injuries, especially if incurred frequently, are shown to be a significant risk factor for adverse behaviours in children. Due to the lack of temporal precedence, however, causal conclusions cannot be definitively drawn.

In contrast, a recent cross-sectional study from the University of Calgary used multiple regression analyses to predict BASC-2 Anxiety and Depression subscale scores from number of previous concussions, and no relationship was found (Plourde et al., 2018). Additionally, children with a history of one concussion, multiple concussions, or orthopedic injury were directly compared and no differences in current anxiety or depression levels as measured by the BASC-2 were observed; only pre-existing mood or learning problems (e.g., ADHD) predicted current psychological adjustment.

Ellis and colleagues (2015) investigated childhood concussion and psychopathology, with psychiatric diagnoses representing the most extreme levels of behavioural dysfunction. The study found that, of the 20 child athletes (*M* age = 14.2 years) assessed who met criteria for a psychiatric disorder post-concussion, the diagnosis was novel for 16 of the children. The remaining four athletes had a pre-existing psychiatric diagnosis and experienced subjective worsening of those symptoms. These results suggest that for most child athletes, concussion temporally precedes psychiatric diagnosis.

A recent study by Stazyk and colleagues (2017) also found a relation between concussions and depression; at a median time of 3.7 months after injury, 22% of the children in the sample with history of concussion showed depressive symptoms. Depression scores were not, however, related to how many concussions the child had previously sustained. Similar results were found from a retrospective cohort study using data from the National Survey of Children's Health (Chrisman & Richardson, 2014). These data indicated a 3-fold greater risk for current depression in children with a history of concussion compared to children without a concussive history. Number of previous concussions was not examined, and duration of time since last injury was either not recorded or not reported. A stronger relation between concussion history and depression was found for older children (15–17 years) compared to younger children (12–14 years), and there was no relation with sex differences.

While mood disorders have been shown to result from concussive injury, a study by Morgan and colleagues (2015) found that premorbid internalizing disorders can increase risk for adverse outcomes following concussion. Specifically, the authors found that athletes with a premorbid mood disorder were more likely to develop prolonged post-concussive symptoms persisting for at least 3 months following injury than athletes without a premorbid mood disorder. A family history of mood disorders was also found to be a significant predictor of persistent post-concussive symptoms.

In children, early trauma to the brain could be particularly disruptive to the child's psychosocial development, which may contribute to post-concussive internalizing behaviours. A return-to-play protocol is recommended for athletes following concussion to reduce the risk of adverse psychosocial outcome (McCrory et al., 2005), as is a graded

return-to-learn protocol for scholastic activities, encouraging students to return to school only when completely asymptomatic (Master, Gioia, Leddy, & Grady, 2012). A prolonged absence from school following concussion, however, may result in changes in relationships with peers, perceptions of social acceptance, and feelings of isolation, all of which may contribute to internalizing behaviours (DeMatteo et al., 2015; Karlin, 2011). For athletes, the same cognitive and behaviour patterns may result from a prolonged absence from sports. In the qualitative study by Caron and colleagues (2013), all athletes interviewed discussed pervasive feelings of isolation following their concussion, suggesting that across both school and sports, lack of peer interactions following concussion may contribute to the development of internalizing behaviours.

1.6.2 Externalizing behaviours. Externalizing behaviours are characterized by disinhibition, such as hyperactivity, impulsivity, aggression, or conduct problems (S. M. King et al., 2004). Given that behavioural inhibition is largely mediated by the frontal lobes, a brain area commonly disrupted in concussion, it is not surprising that externalizing behavioural problems are often reported following concussive injury (Bryant, 2008; Daneshvar et al., 2011).

Seichepine and colleagues (2013) administered the Behaviour Rating Inventory of Executive Functioning (BRIEF), which includes a behavioural inhibition subscale, to 64 current and retired male football players aged 25 to 81 with a history of mild TBI. The results indicated a significant difference in *T*-scores for the inhibition subscale, with football players reporting more problems with inhibition compared to the normative sample. The corresponding standardized mean difference was 0.85, indicating a large effect. Again, causal conclusions cannot be definitively drawn. It may be that individuals

with lower behavioural inhibition are more likely to become concussed, or more likely to become athletes, or more likely to stay in the sport longer before retiring.

Kerr and colleagues (2014) conducted a similar study to investigate how previous concussions predicted impulsivity and aggression among 797 retired collegiate athletes. A short form of the Barratt Impulsiveness Scale (Patton, Stanford, & Barratt, 1995) and a short form of the Buss-Perry Aggression Questionnaire (Buss & Perry, 1992) were used as outcome measures. After controlling for covariates, including demographic variables, alcohol dependence, education, and family history of mental illness, results indicated that impulsivity scores were higher for former athletes reporting two previous concussions compared to those reporting none. Athletes reporting three previous concussions had higher impulsivity scores than those reporting two or fewer. In terms of aggression, after controlling for covariates, former athletes reporting three or more concussions had higher mean scores for aggression compared to those reporting no previous concussions.

Taken together, these results suggest a relationship between concussion and externalizing behaviours, including aggression and difficulties with behavioural inhibition. This link may be due to differential susceptibility to concussion because of premorbid behavioural problems. Individuals who are more aggressive, impulsive, and have more difficulty controlling their behaviour may be more likely to sustain concussions. Alternatively, this association may represent an increased vulnerability to behavioural inhibition difficulties following concussive injury. Unfortunately, much of the literature does not include baseline estimates of externalizing behaviours.

Concussion and externalizing behaviours in children. Studies investigating externalizing behaviours in children following concussion are sparse. One of the few

studies to directly assess this construct was Liu and Li's (2013) large cohort study of 6-year-old Chinese schoolchildren. Results demonstrated a linear relationship between number of previous mild head injuries and externalizing behaviour problems as rated by the parent using the CBCL. When externalizing behaviour scores were converted to binaries of having a behavioural problem or not (using clinical cutoffs described in the CBCL manual), the adjusted odds ratio (controlling for covariates) for the externalizing behaviour composite was 4.03. In other words, increasing the number of previous mild head injuries by one renders a child 4.03 times more likely to score above the clinical cutoff for behavioural problems. This odds ratio is higher than the internalizing behaviour composite, which yielded an adjusted odds ratio of 2.76. Furthermore, when the Aggression subscale of the externalizing composite was investigated, the resulting odds ratio was 6.03. This indicates that a one-unit increase in number of previous mild head injuries renders a child 6.03 times more likely to score above the clinical cutoff for aggressive behaviour.

A similar study by Brooks and colleagues (2016) examined the prevalence of ADHD in relation to concussion history among high school students. The authors found that male high school football players with prior concussions were more likely to have a diagnosis of ADHD compared to male high school football players without prior concussions. Additionally, athletes with ADHD reported more post-concussive symptoms than athletes without ADHD. Similar results were found in a study by Iverson and colleagues (2015), in which a diagnosis of ADHD was a significant predictor of baseline reporting of post-concussive symptoms among high school students, indicating that there

is a link between ADHD and post-concussive symptomology in the absence of concussion.

Miller and colleagues (2016) extended these findings to a wider age group. In a study of children aged six through 18 years who sought treatment at a local concussion clinic following head injury, results indicated that ADHD was a significant predictor of prolonged recovery following concussion. Specifically, a history of ADHD was associated with 4.41 times greater odds of post-concussive symptoms persisting beyond 28 days. This finding further supports the link between concussion and ADHD in children.

Despite these observed relationships between externalizing behaviours and concussion among children, it remains unclear whether externalizing behaviours are the result of concussion, a risk factor for concussion, or both, suggesting a reciprocal causality. Max and colleagues (2004) investigated the prevalence of post-injury ADHD compared to pre-injury ADHD in a sample of children aged 5 through 18 who presented with varying degrees of TBI. Their results indicated that prevalence of post-injury ADHD increased with TBI severity, with severe TBI patients showing the greatest number of diagnoses and mild TBI patients showing the fewest number of diagnoses. Additionally, among the patients with moderate TBI, post-injury ADHD occurred only in the presence of pre-injury ADHD traits. While it is possible to develop ADHD following a TBI despite not having pre-injury ADHD, this pattern was more common in children who experienced severe brain injury rather than mild injury.

McKinlay and colleagues (2009) examined behavioural outcomes of mild TBI longitudinally. Specifically, they followed a birth cohort of children who were either

hospitalized for mild TBI before age 5 years, treated as an outpatient for mild TBI before age 5, or had no experience with mild TBI. The cohort was assessed in adolescence to determine the presence of behavioural problems, with outcome measures including the Revised Behaviour Problem Checklist (Quay, 1983), the Self-Report Early Delinquency Scale (Moffitt & Silva, 1988), and the Diagnostic Interview Schedule for Children (Costello, Edelbrock, Kalas, Kessler, & Klaric, 1982). Results indicated that, at age 14 to 16 years, children who had been hospitalized for mild TBI before age 5 were significantly more likely to show symptoms of ADHD and conduct disorder or oppositional defiant disorder compared to the healthy controls. In contrast, children who had been treated for mild TBI as outpatients did not differ in incidence from the control group. These findings again suggest that more severe cases of brain injury are more likely to be associated with subsequent externalizing behavioural problems.

In summary, the literature yields conflicting findings regarding the association between externalizing behaviours and TBI. While some researchers have found significant effects of concussion on externalizing behaviours (e.g., Liu & Li, 2013), it may be that having greater levels of baseline behaviour problems predisposes athletes to future concussions. Although researchers who used rigorous methodology found the effect to be limited to cases of more severe brain injury (Max et al., 2004; McKinlay et al., 2009), the potential for multiple concussive injuries (as opposed to one) as a contributory factor to externalizing behaviour was not investigated. Thus, there is no consensus among empirical research on the relationship between multiple concussions and externalizing behaviours.

Although there are more studies on the relationship between internalizing behaviours and concussion, most have focused on adult populations. To date, only one study has examined the link between the number of previous mild head injuries and current internalizing behaviour in children and results indicated a dose-response association between number of previous mild head injuries and internalizing behaviour. Generalizability, however, is difficult due to the limited demographics of the sample. No other known published studies have examined the link between multiple concussions and internalizing behaviour in children.

1.7 Thesis Objectives

The importance of thoroughly understanding the associations between recurrent concussions in childhood and internalizing behaviours and externalizing behaviours cannot be overstated. As most research on the relations between behavioural disorders and concussion has been conducted on adult populations, little, if anything, is known about how these associations affect children. A more thorough understanding of the nuances of childhood internalizing and externalizing behaviour as they relate to concussion is crucial to help identify children who are most at risk for developing behavioural disorders following one or more concussions. Understanding these nuances will also help to identify the behaviours that may put children at risk for future concussions.

Because baseline levels of behaviour cannot be experimentally manipulated, it is difficult to determine the direction of causality between concussions and behaviour. However, predictive models can be used to estimate who is at risk for behavioural disorders following one or more concussions and who is at risk for future concussions

based on present behaviour. The first step to achieving this goal is to determine whether there is an association between multiple concussions and psychological adjustment, particularly after controlling for covariates.

The goal of the present research was to evaluate how current psychosocial adjustment relates to concussion history among male and female child athletes. Current behaviour, as assessed by the Behaviour Assessment System for Children – Third Edition (BASC-3), was used in a logistic regression model to predict the number of previous concussions the athlete has sustained. This study will build a framework for future researchers such that they can predict the likelihood or severity of behavioural problems based on the number of concussions an athlete has sustained.

1.7.1 Hypotheses.

- 1) Measures of baseline internalizing and externalizing behaviour will be significant predictors of the number of previous concussions an athlete has sustained (zero, one, or multiple); in other words, a multinomial logistic regression model utilizing both internalizing and externalizing behaviour as predictors will be statistically significant overall and will show good model fit.
- 2) Internalizing and externalizing behaviours alone will be significant predictors of the number of previous concussions an athlete has sustained (zero, one, or multiple); in other words, each predictor alone will show a statistically significant Wald statistic and an odds ratio above 1.
- 3) Internalizing and externalizing behaviour will be significant predictors of past concussive frequency after controlling for covariates which may include cognitive status (as measured by the Immediate Post-Concussion Assessment and Cognitive Testing; Lovell

et al., 2000), presence and severity of baseline post-concussive symptoms (as measured by the Post-Concussion Symptom Scale), duration since last concussion, and socioeconomic status (as measured by parental education history).

Due to the paucity of research on sex differences as they relate to concussion and behaviour among child athletes, there are no a priori hypotheses regarding differences between males and females.

CHAPTER 2. METHODOLOGY

2.1 Participants

The present study made use of archival data collected by the University of Windsor's Sport-Related Concussion Centre (SRCC) as part of a baseline assessment protocol among community minor hockey leagues in the Windsor-Essex area. Participants included travel league hockey players recruited from the Sun Parlour Female Hockey Association ($n = 21$), and Windsor AAA Zone ($n = 1$), and travel league soccer players recruited from the Tecumseh Soccer Club ($n = 26$). Most participants were accompanied by their parents and tested in groups of up to 17 players, this represented the number of players on a hockey team. Although players were encouraged to undergo a baseline assessment at the beginning of the hockey season and to return for re-assessment following concussion, only baseline data was used for the present study.

2.2 Measures

2.2.1 The Behaviour Assessment System for Children – Third Edition (BASC-3; Reynolds & Kamphaus, 2015). The BASC is a well-validated and comprehensive instrument designed to assess childhood psychopathology and behavioural disorders. There are three forms: parent-, teacher-, and child-completed. The Parent Rating Scales (PRS) is a measure of the child's adaptive and problem behaviours in home and community settings, as rated by the parent. The assessment produces norm-referenced *T*-scores for all subscales, as well as four overarching composite scales that indicate how the child's behaviour compares to his or her peers. The two composite scales being investigated for the present study are the Internalizing Problems Index and

the Externalizing Problems Index. For more detailed information about the PRS, see Appendix A.

BASC-3 Internalizing Problems Index. The Internalizing Problems Index is the composite of three subscales: Anxiety, Depression, and Somatization. Anxiety refers to the tendency to be nervous, fearful, or worried about real or imagined problems, and excessive worry is a central characteristic measured by this subscale. Other measured anxiety behaviours include phobias, self-deprecation, and nervousness. The Depression scale measures feelings of unhappiness, sadness, and stress that may result in an inability to carry out day-to-day activities. The Somatization scale measures the tendency to be overly sensitive to and to complain about minor physical aches and pains. Somatization scale items also include fears of illness and complaints about health. Validity and reliability statistics for the Internalizing Problems Index are discussed in Appendix B.

BASC-3 Externalizing Problems Index. The Externalizing Problems Index measures the general disruptive nature of a child's behaviour. Children high in externalizing problems, as measured by this subscale, tend to disrupt the activities of both peers and adults, are often unresponsive to adult direction, and have problematic relationships with peers. The Externalizing Problems Index comprises three subscales: Aggression, Conduct Problems, and Hyperactivity. The Aggression scale measures the child's tendency to act in a hostile manner, either verbally or physically. This scale also assesses more general aggressive behaviours such as getting revenge and bullying. The Conduct Problems scale measures disruptive and socially deviant behaviours, including the child's tendency to engage in antisocial and rule-breaking behaviour. The Hyperactivity scale assesses the hyperactive and impulsive behaviours that are often seen

in ADHD. Validity and reliability statistics for the Externalizing Problems Index are discussed in Appendix B.

BASC-3 Validity scales. The BASC-3 provides three validity scales to help determine the quality of the response profile. Factors that can threaten validity include inattention to item content, poor comprehension of items, lack of motivation to respond truthfully, or an attempt to portray the child in an overly negative or positive light. The three validity scales included in the PRS are the Response Pattern Index, the Consistency Index, and the F Index. These scales are designed to detect inattention to item content, inconsistent responding, and an overly negativistic response pattern, respectively. The validity scales each generate a categorical scale of *Acceptable*, *Caution*, or *Extreme Caution*. Within the norm sample, 3–6% of cases fell in the *Caution* or *Extreme Caution* range, indicating that most respondents do not fail any validity Indexes. For the present study, all participants fell in the *Acceptable* range for all scales.

2.2.2 The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT; Lovell, Collins, Podell, Powell, & Maroon, 2000). The ImPACT is a computerized neurocognitive test battery and symptom inventory designed for use with athletes who may experience concussions. The ImPACT is typically administered at baseline and following a concussion; for the purposes of this study, only the athletes' baseline data was used.

The ImPACT is a 25 minute assessment consisting of (1) a series of demographic questions regarding height, weight, sport, position, concussion history, history of learning disabilities, and other important descriptive information; (2) the Post-Concussion Symptom Scale (PCSS), which is a 22-item questionnaire assessing the presence and

severity of 22 symptoms commonly associated with concussion; and (3) six testing modules that assess several facets of cognition, including learning and memory, attentional processes, and visual motor abilities (ImPACT Technical Manual, 2011). The overall sensitivity and specificity of the ImPACT in classifying cases as being concussed or non-concussed have been shown to be 81.9 percent and 89.4 percent, respectively (Schatz, Pardini, Lovell, Collins, & Podell, 2006). Validity of the ImPACT has also been measured by comparing performance on the ImPACT against performance on similar neuropsychological test batteries (e.g., Allen & Gfeller, 2011; Iverson, Franzen, Lovell, & Collins, 2003; Iverson, Lovell, & Collins, 2005). Overall validity has been found to be good. The ImPACT clinical report yields six composite scores; three are measures of cognitive ability (Verbal Memory Composite, Visual Memory Composite, and Visual Motor Speed Composite), the fourth measures reaction time, the fifth measures impulse control, and the sixth is the total symptom score for the PCSS (ImPACT Technical Manual, 2011).

ImPACT Verbal Memory Composite. This composite scale measures attentional processes, learning, and memory within the verbal domain (ImPACT Technical Manual, 2011). It represents an average of scores obtained on three cognitive modules: Word Memory, Symbol Match, and Three Letters. Test-retest reliability among athletes aged 11 to 14 years is fair (ICC = 0.58; O'Brien, Casey, & Salmon, 2017), and among high-school athletes ranges from fair to good (ICCs = .48–.62; Brett & Solomon, 2017; Elbin, Schatz, & Covassin, 2011).

ImPACT Visual Memory Composite. This composite scale measures visual attention and scanning, and learning and memory within the visual domain (ImPACT

Technical Manual, 2011). This composite score represents an average of scores obtained on two cognitive modules: Design Memory and X's and O's. Test-retest reliability among athletes aged 11 to 14 is fair (ICC = .54; O'Brien, Casey, & Salmon, 2017), and among high-school athletes ranges from fair to good (ICCs = .49–.70; Brett & Solomon, 2017; Elbin, Schatz, & Covassin, 2011).

ImPACT Visual Motor Speed Composite. This composite scale evaluates visual processing ability, learning and memory, and visual-motor response speed (ImPACT Technical Manual, 2011). This composite score represents an average of scores obtained on two cognitive modules: X's and O's (Interference Stage) and Three Letters (Countdown Phase). Test-retest reliability among athletes aged 11 to 14 is excellent (ICC = 0.84; O'Brien, Casey, & Salmon, 2017), and among high-school athletes is excellent (ICCs = .79–.81; Brett & Solomon, 2017).

ImPACT Reaction Time Composite. This composite scale evaluates average response speed (ImPACT Technical Manual, 2011). This composite score represents an average of correct response times on three different modules: X's and O's (Interference Stage), Symbol Match, and Color Match. The composite score represents the grand mean of all correct reaction times across these three modules. Test-retest reliability among athletes aged 11 to 14 is fair (ICC = 0.54; O'Brien, Casey, & Salmon, 2017), and among high-school students ranges from fair to good (ICCs = .52–.76; Brett & Solomon, 2017; Elbin, Schatz, & Covassin, 2011).

ImPACT Impulse Control Composite. This composite scale is a measure of errors on testing and is useful in evaluating test validity (ImPACT Technical Manual, 2011). This composite score represents the sum of two scores: total incorrect on the

Interference Phase of X's and O's, and total errors of commission on Color Match. A score above 30 is considered invalid (ImPACT Technical Manual, 2011). Test-retest reliability has not been assessed. As there is no singular global composite representing overall cognitive status as measured by the ImPACT, the Visual Motor Speed Composite will be used as the covariate representing cognitive status because it is the most reliable composite score. For a more detailed justification of the use of this composite to represent overall cognitive status, see Appendix E.

ImPACT Post-Concussion Symptom Scale (PCSS) Total Symptom Composite.

This questionnaire instructs athletes to rate their current experience of 22 symptoms commonly associated with post-concussive injury on a scale of 0 (*not present*) to 6 (*severe*; ImPACT Technical Manual, 2011). Symptoms assessed include such things as headache, nausea, sensitivity to light, and irritability (see Appendix C for full list of symptoms). The Total Symptom Composite represents the 22 ratings, ranging from a minimum score of 0 (if all symptoms were rated as “not present”) to a maximum score of 132 (if all 22 symptoms were rated as “severe”). Scores are not converted to percentile rankings in the clinical report; however, classification ranges and corresponding percentile ranking ranges are provided, based on normative data, in the ImPACT Technical Manual (2011). Specifically, among high-school girls, a total score of 0 falls in the Low-Normal range (percentile rank = 29.4), a total score of 1–8 falls in the Normal range (percentile rank = 40–75), 9–17 falls in the Unusual range (percentile rank = 76–90), 18–39 falls in the High range (percentile rank = 91–95), and 40+ falls in the Very High range (percentile rank > 95). Test-retest reliability among athletes aged 11 to 14 is excellent (ICC = 0.90; O'Brien, Casey, & Salmon, 2017), and estimates of test-retest

reliability among high-school and college students range from moderate to good (Pearson's $r = .40-.80$, ICC = .57; Elbin, Schatz, & Covassin, 2011; ImPACT Technical Manual, 2011). Cronbach's alpha is excellent (estimates range from .88 to .94; ImPACT Technical Manual, 2011).

ImPACT Validity Report. The ImPACT contains five performance validity indicators. Failure of only one indicator designates the ImPACT evaluation as questionable. Although there are other sets of performance validity indicators that have been published for the ImPACT, the default set will be used, as it is the most conservative in terms of the proportion of invalid cases identified (Abeare, Messa, Zuccato, Merker, & Erdodi, Submitted). In the present study, no cases were marked as having questionable validity.

2.2.3 Demographic questions. Although the ImPACT includes a demographic questionnaire, an additional demographic questionnaire created by SRCC staff was included to gain information needed for the present study. For example, additional demographic questions include items regarding parents' levels of education (i.e., *How many years of education has each parent of the child received?*), as less parental education has been associated with a history of multiple concussions and a greater incidence of behavioural problems (Kalff et al., 2001; Liu & Li, 2013). See Appendix D for the full questionnaire.

Additional demographic questions also include a thorough assessment of concussion history. Anecdotally, the SRCC has found that athletes do not always know when they have experienced a concussion. In other words, asking questions such as, "how many concussions have you experienced?" may prove to be an inaccurate measure

of concussion history. Therefore, the additional demographic questions avoid using the term “concussion” and instead includes items such as, *“Has your child ever experienced an injury resulting in a hit to the head or jaw that caused confusion and one or more of the following symptoms: headache, nausea, vomiting, dizziness/balance problems, fatigue, trouble sleeping, drowsiness, sensitivity to light or noise, blurred vision, difficulty remembering, and difficulty concentrating?”* For each “yes”, the parent is instructed to estimate the date of injury, method of injury (i.e., as the result of playing sports, falling, motor vehicle accident), main symptoms experienced, and duration of symptoms. These additional demographic questions are designed to enable an accurate evaluation of concussion history, in order to enhance the validity of the interpretation of the results.

2.3 Procedure

Participants completed their baseline assessments through the SRCC at the University of Windsor. Participants were scheduled for group sessions such that team members would participate together, accompanied by their parents. On the day of assessment, players arrived at the computer lab of the University of Windsor’s Human Kinetics building where were greeted by graduate students assisting with the administration of the baseline protocol. Once all team members had arrived, a brief presentation was given by the supervising clinical neuropsychologists explaining the purpose of the baseline engagement sessions and what to expect throughout the assessment process. The speech also included informative facts about sport-related concussions, steps to take if a concussion has been suspected, and what to expect throughout recovery from concussion.

As part of the baseline assessment, parents were provided via email the link to an online survey containing the electronic consent form and demographics questionnaire (Appendix D). Once completed, they were emailed the parent-report form of the BASC-3. The BASC-3 online interface contains all instructions needed to complete the form. Once the BASC-3 was completed, a report containing the child's scores was generated using the interactive online software.

Following the completion of child assent forms, players began the demographic module of the ImPACT with assistance as needed from their parents. This was followed by the PCSS. After all players had completed the PCSS, parents were asked to leave the room, and the athletes were asked to remain quiet for the remainder of the ImPACT. This was to ensure a quiet, non-distracting environment for the players to complete the cognitive modules of the ImPACT. If athletes had questions, they were instructed to raise their hand so as not to disturb other athletes. Athletes were separated by at least one seat so as not to distract each other.

As part of the baseline assessment procedure, players were also asked to undergo balance testing in another room of the Human Kinetics Building. Because this data was not used for the present study, the balance testing procedure will not be further detailed.

In the days following data collection, clinical reports were automatically generated for the players using the ImPACT's online software. Composite scores were then recorded. As this protocol was part of a larger operation by the SRCC to provide baseline and post-concussive testing to athletes, players who sustained a concussion were asked to return following their injury for a post-concussive evaluation, which was similar

in nature to the baseline evaluation. However, because the present study utilized baseline data only, post-injury protocols will not be described.

CHAPTER 3.

RESULTS

3.1 Approach to Data Analysis

To investigate the relationship between the number of previous concussions a player has sustained (zero, one, or multiple) and their baseline levels of externalizing and internalizing behaviour, a multinomial logistic regression using the Internalizing Problems Index and Externalizing Problems Index as predictor variables would have been ideal. Due to difficulties outside of the author's control, with recruitment yielding a smaller sample size than was desired, there were not enough athletes in each stratification of concussion history to properly conduct a multinomial logistic regression.

Hosmer and colleagues (2013) suggest a sample size of at least 10 cases per predictor per group for a logistic regression analysis. This should be equivalent to, at minimum, 60 cases, given the two primary predictor variables and three outcome groups (zero, one, or multiple concussions). The present sample included 48 participants, but only 8 of those had a concussion history, thus a multinomial logistic regression would have been severely underpowered. Therefore, the decision was made to collapse across groups for athletes with a positive history for concussion, yielding a dichotomous outcome: zero concussions versus one or more concussion.

It is important to note that this test is still underpowered when using only the two primary predictors, as there should be at least 20 participants with a concussion history to achieve adequate power (Hosmer, Lemeshow, & Sturdivant, 2013). Had the two primary predictors been significant correlated, they could have been merged into one predictor that would represent general behavioural problems, but they were not ($r = .16, p > .05$).

All analyses were conducted using SPSS Statistics 25.0. For the logistic regression analysis, *T*-scores from the BASC-3 (Internalizing Problems Index and Externalizing Problems Index) were entered as primary predictors, and history of previous concussions (0 versus 1+) was entered as the binary outcome variable. The number of previous concussions sustained was determined from parent answers on the demographics form created by our lab. Because the analysis was already underpowered, the decision was made to omit all potential covariates from the model and instead examine them descriptively.

Due to the limitations outlined above, the three hypotheses for the present study were deemed untestable. Instead, a new hypothesis was proposed that could be answered using binomial logistic regression. This hypothesis is an amalgamation of original hypotheses 1 and 2 and predicts that measures of baseline externalizing and internalizing behaviour will be significant predictors of an athlete's concussive history (0 versus ≥ 1 concussion); in other words, the logistic regression model will show overall statistical significance and good model fit, and both predictors will show significant Wald statistics and odds ratios above 1.

3.2 Data Cleaning and Analysis of Assumptions

Prior to hypothesis testing, the data were analyzed to determine adherence to the assumptions of logistic regression. Assumptions examined include a categorical or ordinal outcome variable, independence of observations and errors, linearity of the logit, absence of complete separation of groups, lack of incomplete information about predictors, absence of overdispersion, and absence of multicollinearity. Rather than an inability to conduct MLR, violations of several of these assumptions result in a greater

likelihood of finding incorrect results (either false positives or false negatives).

Assumptions were tested for all variables that could potentially be included in the logistic regression analysis (i.e., both BASC-3 Indexes as well as the potential covariates of sex, time since last concussion, cognition, PCSS Total Symptoms Composite, and average parent education. For details about how these covariates were operationalized and assessed, see Appendix E).

The assumption of lack of incomplete information about predictors was violated, likely because there were so few cases of the event occurring (i.e., an athlete with a positive concussion history) to predict. The assumption of lack of absence of complete separation of groups was violated for the covariate *time since last concussion*, but remains met so long as that covariate is not included in any analyses. All other assumptions were met. For detailed descriptions of assumptions, including how they were assessed and determined to be met or violated, see Appendix F.

3.2.1. Missing data. Three cases were found to have missing data. One case (female, zero previous concussions) was missing data for the BASC-3 Internalizing Problems Index and Anxiety Subscale as her parent failed to complete part of the BASC-3 questionnaire that contributed to these composites. Two cases (one male with one previous concussion, one female with zero previous concussions) were missing data for all components of the ImPACT as one had not completed it and the other's data could not be accessed. The total percentage of missing data in the present sample was 2.01%, and Little's MCAR test was not significant, $\chi^2(70) = 73.54, p = .363$, indicating that these data were missing completely at random. Thus, multiple imputation was utilized for handling missing data.

Multiple imputation has been described as superior to listwise deletion in almost all circumstances (Manly & Wells, 2014). Several variables were included in the imputation phase to increase imputation accuracy; these included the BASC-3 Internalizing Problems Index and Externalizing Problems Index, the three subscales contributing to each of those indexes (Depression, Anxiety, and Somatization contribute to the Internalizing Problems Index; Hyperactivity, Aggression, and Conduct Problems contribute to the Externalizing Problems Index), and all of the composites yielded from the ImPACT (Verbal Memory Composite, Visual Memory Composite, Visual Motor Speed Composite, Reaction Time Composite, and PCSS Total Symptoms Scale Composite). The BASC-3 Externalizing Problems Index and its constituent subscales did not have any missing data, but were included to aid achieving greater accuracy for the imputed values.

The imputation was computed using SPSS (IBM SPSS Statistics for Macintosh, Version 25.0); the number of imputations was set at 5, and potential values for the imputed data were constrained at the maximum and minimum observed value for that variable. SPSS automatically chose a method of imputation based on a scan of the data. All missing values were successfully imputed, and the pooled data were used for all subsequent analyses.

3.3 Demographic Information

Data pertaining to participant demographics including history of concussion and neurodevelopmental disorders were collected for the purpose of sample description. Demographic variables include participant's age, gender, ethnicity, sport played, parental level of education, history of concussion/head injury, and presence of

Table 1. *Basic Demographic Characteristics of Participants (N=48)*

Characteristic	Mean (SD) or n (%)
Age (Years)	12.95 (0.55)
11	6 (12.5%)
12	15 (31.3%)
13	26 (54.2%)
14	1 (2.1%)
Sex	
Female	37 (77.1%)
Male	11 (22.9%)
Ethnicity	
Caucasian/White	36 (75.0%)
Asian	1 (2.1%)
Black/African-Canadian	2 (4.2%)
Hispanic	1 (2.1%)
Mixed/Bi-Racial	4 (8.3%)
No response	4 (8.3%)
Sports Organization	
SPFHA (Hockey)	21 (43.8%)
TSC (Soccer)	26 (54.2%)
Windsor AAA (Hockey)	1 (2.1%)
Number of Previous Concussions	
0	40 (83.3%)
1	5 (10.4%)
2	3 (6.3%)
Parent Education (Years)	15.03 (1.80)

Note. SPFHA = Sun Parlor Female Hockey Association; TSC = Tecumseh Soccer Club

psychological disorders or learning disabilities.

The final sample consisted of 48 participants, with females representing 77.1% of the sample. The ages of participants ranged from 11 to 14 years old. The majority of the sample (75%) self-identified as being of Caucasian descent, and the majority of parents had completed some post-secondary education (mean years of parental education per child = 15.03). See Table 1 for basic demographic information.

The psychological and neuropsychological characteristics of the sample are described in Table 2. Most of the sample reported no previous clinical diagnoses, and mean *T*-scores for the BASC-3 Indexes and subscales were all within the Normal classification range (defined as $T < 60$). For the Externalizing Problems Index, no athlete scored in the At-Risk range ($T \geq 60$) or in the Clinically Significant range ($T \geq 70$). For the Internalizing Problems Index, two athletes scored in the At-Risk range, and no athlete scored in the Clinically Significant range. These BASC-3 scores indicate that internalizing and externalizing behaviour problems were virtually absent in the sample. The average PCSS Total Symptoms Composite score across participants was 4.67, suggesting that few participants were experiencing post-concussive symptoms at the time of evaluation.

Slightly fewer than one fifth of participants ($n = 8$) reported having a history of at least one concussion according to parental report, and of those eight, three reported a history of two previous concussions. On average, the most recent concussion among the eight participants with a concussion history happened over two years ago, although the range extended from 25 days to 5.5 years. Among athletes with a history of concussion,

Table 2. *Psychological and Neuropsychological Characteristics of Sample (N=48)*

Characteristic	Mean (SD) or n (%)	Range
Clinical Diagnosis ^a		
Learning Disability	1 (2.1%)	
ADHD	2 (4.2%)	
Anxiety	3 (6.3%)	
Depression	1 (2.1%)	
No Previous Diagnoses Reported	44 (91.7%)	
BASC-3 Composite Scores (T-Score) ^b		
Externalizing Problems Index	47.25 (4.48)	40–58
Internalizing Problems Index	48.2 (6.77)	36–62
BASC-3 Subtest Scores (T-Score) ^b		
Hyperactivity	47.87 (7.40)	38–68
Aggression	47.77 (3.73)	41–58
Conduct Problems	46.71 (4.40)	39–57
Anxiety	50.52 (9.84)	33–75
Depression	47.25 (6.18)	39–68
Somatization	47.58 (6.25)	36–63
ImPACT Composite Scores (Raw) ^c		
Verbal Memory	83.28 (9.38)	53–99.2
Visual Memory	71.00 (12.06)	49–100
Reaction Time	0.69 (0.13)	0.50–1.23
Visual Motor Speed	31.85 (5.63)	22–47
PCSS Total Symptoms Composite	4.93 (6.24)	

Notes. ADHD = Attention-Deficit Hyperactivity Disorder; ImPACT = Immediate Post-Concussion Assessment and Cognitive Testing; PCSS = Post-Concussion Symptom Scale.

^aClinical diagnoses are not mutually exclusive; of the four athletes who reported a diagnoses, one (33.3%) endorsed more than one diagnosis.

^bBASC-3 scores are standardized to *T* scores such that higher values reflect greater behavioural problems. Scores below 60 are considered to fall in the Normal range.

^cAll ImPACT raw scores, with the exception of Reaction Time, are scored such that higher scores represent better performance. Reaction Time is scored such that higher scores represent greater time (i.e., worse performance).

half were male and half were female. Descriptive statistics for both groups can be found in Table 3.

3.3.1. Sex differences. One of the goals of this study was to investigate sex differences in concussion history among athletes and to examine the extent to which sex contributes to the logistic regression model. Due to limited sample size, it was not feasible to include sex as a covariate in the logistic regression model. Therefore, sex differences were examined using alternative methods.

To examine the relation between sex and concussion history, a chi-square test was conducted comparing males and females on concussion history (negative versus positive). Due to the criticisms of using the Pearson chi-square statistic with small samples (A Field, 2013), the likelihood ratio was instead examined. This statistic yielded a nonsignificant result, $LR(2) = 4.03, p = .134$, indicating that males and females do not significantly differ in their concussion history. Sex differences for other variables including ImPACT test scores and BASC-3 composite scores were examined descriptively and are outlined in Table 5.

3.4 Primary Analyses

A binary logistic regression was conducted to investigate the extent to which behavioural problems as rated by parents on the BASC-3 (BASC-3 Internalizing Problems Index, BASC-3 Externalizing Problems Index) predicted previous concussion history (0 concussion vs. 1+ concussion). As noted previously, due to the limited sample size, no covariates were included in the model.

Table 3. Comparing Athletes With and Without a Concussion History

Characteristic	Mean (<i>SD</i>) or <i>n</i> (%)	
	0 Previous Concussions (<i>n</i> = 40)	≥ 1 Previous Concussions (<i>n</i> = 8)
Age (Years)	12.95 (0.71)	12.94 (0.23)
Sex		
Female	33 (82.5)	4 (50.0%)
Male	7 (17.5)	4 (50.0%)
Avg. Parent Education (Years)	14.88 (1.68)	15.81 (2.27)
Days Since Last Concussion	-- --	826.38 (769.69)
BASC-3 Composite Scores (T-Score) ^a		
Externalizing Problems Index	47.03 (4.67)	48.38 (3.20)
Internalizing Problems Index	48.74 (7.01)	45.50 (4.90)
BASC-3 Subtest Scores (T-Score) ^a		
Hyperactivity	47.63 (7.75)	49.13 (5.59)
Aggression	47.48 (3.73)	49.25 (3.62)
Conduct Problems	46.75 (4.57)	46.50 (3.63)
Anxiety	51.48 (10.22)	45.88 (7.02)
Depression	47.93 (6.42)	43.88 (3.34)
Somatization	47.57 (6.58)	47.63 (4.57)
ImPACT Composite Scores (Raw) ^b		
Verbal Memory	82.60 (9.84)	86.84 (6.51)
Visual Memory	70.88 (11.65)	71.74 (15.27)
Reaction Time	0.68 (0.10)	0.80 (0.23)
Visual Motor Speed	31.77 (5.80)	32.21 (5.23)
PCSS Total Symptoms Composite	4.65 (6.49)	6.65 (5.30)

Notes. ImPACT = Immediate Post-Concussion Assessment and Cognitive Testing; PCSS = Post-Concussion Symptom Scale.

^aBASC-3 scores are standardized to *T* scores such that higher values reflect greater behavioural problems. Scores below 60 are considered to fall in the Normal range.

^bAll ImPACT raw scores, with the exception of Reaction Time, are scored such that higher scores represent better performance. Reaction Time is scored such that higher scores represent greater time (i.e., worse performance).

Table 4. *Sample Characteristics of Females vs. Males*

Characteristic	Mean (<i>SD</i>) or <i>n</i> (%)	
	Female (<i>n</i> = 37)	Male (<i>n</i> = 11)
Age (Years)	12.90 (0.72)	13.12 (0.31)
Parent Education (Years)	15.08 (1.79)	14.86 (1.92)
Number of Previous Concussions		
0	33 (89.2%)	7 (63.6%)
1	3 (8.12%)	2 (18.2%)
2	1 (2.70%)	2 (18.2%)
BASC-3 Composite Scores (T-Score) ^a		
Externalizing Problems Index	47.16 (4.30)	47.55 (5.24)
Internalizing Problems Index	49.10 (6.74)	45.18 (6.24)
BASC-3 Subtest Scores (T-Score) ^a		
Hyperactivity	47.59 (7.33)	48.82 (7.92)
Aggression	47.54 (3.34)	48.55 (4.95)
Conduct Problems	47.05 (4.37)	45.55 (4.48)
Anxiety	51.63 (9.60)	46.91 (10.58)
Depression	48.27 (6.27)	43.82 (4.60)
Somatization	47.89 (6.55)	46.55 (5.20)
ImPACT Composite Scores (Raw) ^b		
Verbal Memory	82.79 (9.72)	85.07 (8.66)
Visual Memory	69.33 (11.43)	76.72 (13.33)
Reaction Time	0.70 (0.10)	0.67 (0.20)
Visual Motor Speed	31.62 (5.22)	32.58 (7.22)
PCSS Total Symptoms Composite	5.91 (6.64)	1.84 (3.57)

Notes. ImPACT = Immediate Post-Concussion Assessment and Cognitive Testing; PCSS = Post-Concussion Symptom Scale.

^aBASC-3 scores are standardized to *T* scores such that higher values reflect greater behavioural problems. Scores below 60 are considered to fall in the Normal range.

^bAll ImPACT raw scores, with the exception of Reaction Time, are scored such that higher scores represent better performance. Reaction Time is scored such that higher scores represent greater time (i.e., worse performance).

A model including only the intercept was calculated first, to determine the extent to which the outcome can be predicted based only on number of occurrences observed. Given that there were 48 occurrences of a negative concussion history compared to 8 occurrences of a positive concussion history, this model would predict that an athlete with an unknown concussion history was more likely to have had zero previous concussions than one or more. Indeed, this model incorrectly predicted that all 48 participants would have a history of zero concussions.

A test of the full model against the constant-only model was not statistically significant, indicating that the predictors as a set did not reliably distinguish between those with a positive and negative concussion history, $\chi^2(2) = 2.74, p = .254$. Nagelkerke's R^2 of .09 indicates a negligible relationship between prediction and concussion history. Prediction success rate overall was 83.3%, with 100% of those with a negative history of concussion correctly classified, and 0% of those with a positive history of concussion correctly classified. The Wald criterion demonstrated that neither the BASC-3 Externalizing Problems Index, $z = 1.13, p = 0.29$, nor Internalizing Problems Index, $z = 1.99, p = 0.16$, made significant contributions to prediction.

The author advises against scrutinizing the odds ratios for the BASC-3 composite variables, as their 95% confidence intervals both include one. This indicates that the true nature of the relationship in the general population may be such that an increase in the composite variable may increase the likelihood of having at least one previous concussion, or it may decrease the likelihood of having a positive concussion history. Odds ratios for the predictors and the constant can be found in Table 4.

Interestingly, the Hosmer and Lemeshow goodness-of-fit test failed to reach significance, $\chi^2(7) = 6.25, p = .511$, which indicates that there are no statistically significant differences between observed and model-predicted values. In other words, the model was a good fit to the data. In this case, it has already been observed that the model is not clinically useful, given that it correctly predicted 0% of the athletes with a positive history of concussion. It is likely that this result is because there are so few positive occurrences to predict. Thus, the model correctly predicted that no athlete would have a history of concussion, but this finding has negligible clinical value.

Table 5. *Binary Logistic Regression Predicting Concussion History*

Included	95% CI for OR							
	<i>B</i>	<i>SE</i>	Wald	<i>df</i>	<i>p</i>	OR	Lower Bound	Upper Bound
Intercept	-2.09	4.68	0.20	1	0.656	0.12	0.00	1198.80
BASC-3 Externalizing Problems Index ^a	0.10	0.09	1.13	1	0.287	1.10	0.92	1.33
BASC-3 Internalizing Problems Index ^b	-0.09	0.06	1.99	1	0.159	0.91	0.81	1.04

Note. $R^2 = .06$ (Cox & Snell) .09 (Nagelkerke). Model $\chi^2(2) = 2.74, p = .254$

^aBASC-3 scores are standardized to *T* scores such that higher values reflect greater behavioural problems. Scores below 60 are considered to fall in the Normal range.

CHAPTER 4.

DISCUSSION

The purpose of the present study was to investigate the relation between current internalizing and externalizing behaviour and concussion history in children. This was attempted by examining whether BASC-3 composite scores for those behaviours could be used to predict whether a player had previously sustained a concussion. It was hypothesized that a binary logistic regression model would be able to significantly differentiate between athletes with and without a concussion history based on the predictors of internalizing and externalizing behaviour ratings.

Contrary to the hypothesis, the logistic regression did not significantly differentiate the two groups. There was no observable relationship between concussion history and current internalizing and externalizing behaviour in this sample. Neither behavioural predictor made significant contributions to the model, and inspection of the odds ratios and their associated confidence intervals revealed uncertainty regarding whether each behaviour increased or decreased the likelihood of having a history of a concussion. Based on these findings, this suggests that current internalizing and externalizing behaviour as measured by the BASC-3 cannot be used within this sample to reliably predict who has sustained a concussion in the past.

This result is not surprising when the sample is considered. In combination with having a small sample size, most players had not sustained a previous concussion, thus there were few occurrences of concussion history for the model to predict. In the future, a sample that is more evenly split in the outcome variable (i.e., having an equal proportion of those with and without a previous history of concussion) may allow statistical

techniques like logistic regression to more accurately detect differences between groups. Despite the uneven group sizes, the lifetime prevalence of concussion observed in our sample is in line with reported prevalence rates in recent research among children (Ilie, Boak, & Adlaf, 2013; Veliz, McCabe, Eckner, & Schulenberg, 2017). This indicates that the present sample is likely representative of the general population in terms of number of concussions sustained. Thus, one to two hundred athletes may need to be recruited to attain an adequate number of athletes with a history of concussion such that they can be matched with athletes without a history.

Where this sample may not be representative of the general population of child athletes is the level at which these athletes are playing. Typically, sport associations split their teams into “house” teams and the more competitive “rep” or travel teams, where only the top players at a given age group are selected. The athletes in this sample were all part of rep teams. The University of Windsor’s Sport-Related Concussion Centre (SRCC), where the data were obtained, had only recently begun offering a concussion management program to community sports teams, and so far, only the elite rep teams in the surrounding area are part of the program. Part of this may have been due to cost; the SRCC charges \$20 per child for baseline assessments (amounting to approximately \$350 per team), and house leagues may not have the resources to afford these assessments. Indeed, participation per child in a travel league team in Ontario may cost anywhere between \$1,000 to \$5,000 CAD annually per child (Pom, 2014; Watt, 2014), and teams without this financial resource may be less able to afford baseline concussion testing for their players.

The high average socioeconomic status of athletes that participate on travel teams may also have contributed to the very limited clinical variability in BASC-3 scores observed in this sample. Participation in travel league sports can be costly, and families at low income levels may find themselves unable to afford to pay for their child's travel league sports (Watt, 2014). Additionally, investigation of the sample's demographic characteristics found that parents on average have the equivalent of three years of post-secondary education. It has been previously observed that lower parent socioeconomic status is associated with higher levels of problem behaviours (Kalff et al., 2001; Liu & Li, 2013), and thus the high average socioeconomic status of the sample may explain why so few parents endorsed behavioural problems in their children.

Alternatively, the nature of travel league teams may be such that athletes with significant behaviour problems may be dissuaded from participating on such a team. In fact, the online guidelines for one of the travel leagues from which participants were recruited for this study (Tecumseh Soccer Club) states that "players must be mentally tough" and that coaches may not recruit players who are not mentally tough enough to be on the team ("Tecumseh Soccer Club – Tryouts,"). In the field of applied sport psychology, *mental toughness* has been defined as

"having the natural or developed psychological edge that enables you to generally cope better than your opponents with many demands (competition, training, lifestyle)... [and to] be more consistent and better than your opponents in remaining determined, focused, confident, and in control under pressure" (Jones, 2010).

Mental toughness has shown to be associated with higher levels of positive affect and lower levels of negative affect (Mahoney, Gucciardi, Ntoumanis, & Mallet, 2014), thus it is possible that athletes with elevated levels of behaviour problems, especially those relating to negative affect, may not be recruited as often for rep-league teams. Therefore, whereas this sample may be very representative of the average rep-league player, more casual athletes including those playing in house leagues may have higher rates of behaviour problems.

As such, the lack of association found between behaviour problems and concussion history may be true for rep level players only. Without a more diverse sample, it is difficult to know whether these findings would generalize to other populations, including house-league athletes, and even those who are no longer athletes. The present findings are certainly discrepant from what was hypothesized given previous research of behaviour problems in child athletes following concussion (Brooks, Iverson, Atkins, Zafonte, & Berkner, 2016; Ellis et al., 2015). One alternative explanation for why concussion history showed no relationship with behaviour problems in this sample may be that athletes who sustain one or more concussions leading to behavioural problems were more likely to take time off elite sports (or sports all together) and thus would not be present in our sample. Alternatively, the mental toughness required to play sports at such an elite level may be associated with higher resiliency, and thus athletes who go on to sustain one or more concussions may be at a lower risk of developing long-term behavioural problems.

In addition to the restricted sample, another limitation of the present study is the reliance on informant-report measures of behaviour problems. It has been widely

documented in the literature that agreement between parent-reports and self-reports of children's behavioural adjustment tend to be moderate at best (De Los Reyes & Kazdin, 2005; Rescorla et al., 2013). Furthermore, there is evidence to suggest that parent- and self-reports are more discrepant for children ages 12–19 compared to children aged 6–11 (Achenbach, McConaughy, & Howell, 1987), and for internalizing behaviours compared to externalizing behaviours (De Los Reyes & Kazdin, 2005). Social desirability may have also impacted parents' willingness to disclose problematic behaviours in their child; although efforts were made to reassure parents that this information would not be disclosed to their child's coaches or trainers, parents nonetheless may have been more hesitant to report behaviours that may paint their child in an unfavorable light.

4.1 Overlap with Previous Research

There is currently a very limited body of research examining the relation between concussion history and behavioural problems in child athletes. Few studies to date have examined the relationship between history of multiple concussions and behavioural problems, and those that have been conducted have yielded discrepant results. A recent study published in the *Journal of the International Neuropsychological Society* used number of previous concussions to predict Anxiety and Depression subscale scores on the BASC-2 and found no relationship (β values of .09 and .02, respectively; (Plourde et al., 2018). Notably, their sample was similar to that of the present study in that the average time elapsed since last concussion was 2.7 years; in the present sample, the average length of time elapsed since concussion is 2.3 years. It is possible that, in both studies, too much time had elapsed to see any difference between groups. Additionally, both

samples consisted of Canadian families with highly educated parents. High SES may also explain the similarity in results seen between studies.

Conversely, Liu and Li (2013) found a significant association between number of previous concussions and both internalizing and externalizing behaviours, although the relation was stronger for externalizing behaviours. Notably, they found that multiple, but not single, head injuries were associated with increased internalizing and externalizing behaviour. In the present study, concussion history was aggregated so that all participants who experienced one or more concussions fell into the same group. With more participants, it would have been possible to replicate Liu and Li's design such that three groups were compared (0, 1, 2+ concussions) rather than two. Other factors that may account for the differences in observed outcomes between Liu and Li (2013)'s research and the present study include differences in populations and in measures. Liu and Li studied a population of over 1,500 6-year-old Chinese schoolchildren whereas this study included only 48 elite child athletes. Additionally, the Chinese version of the CBCL correlates imperfectly with the BASC-3 (Reynolds & Kamphaus, 2015).

In line with the methodology of Plourde and colleagues (2018), a strength of the present study compared to other previous research is its use of a dimensional measure of behaviour rather than discrete categories (e.g., diagnosis versus no diagnosis). Most of the previously cited studies have relied on diagnoses of a clinical disorder such as depression or ADHD as an outcome variable rather than assessing behaviour on a continuous scale. This reliance on dichotomous indicators of behavioural problems results in the loss of information about the relation between concussion and varying levels of behavioural adjustment. A dimensional measure of behaviour such as the

BASC-3 allows for investigations of subclinical levels of behaviour which would otherwise be lost in a research design that only considers diagnosis versus no diagnosis.

4.2 Implications

Although the present investigation was limited in sample size and sample variability, and it relied entirely on parent reports of behaviour, there are several important implications to highlight. This study should be viewed as evidence that a relationship between concussion and internalizing and externalizing behavioural problems may not exist in this specific population, rather than a failure to replicate previous research. Several hypotheses may explain why elite child athletes might not show behavioural problems following concussion. The elite child athletes may be more resilient, and thus at lower risk of long-term problems, or child athletes with significant behavioural problems following concussion may not continue to play at the elite level. Thus, although direction of causality cannot be inferred, these findings should not be generalized to house-league or other recreational athletes as these populations may demonstrate different relations between concussion and behavioural adjustment.

Future studies should seek to attain wider, more representative samples of athletes to make more broad generalizations about the association between concussion and behaviour problems. Community and high-school recreational sports teams may be more appropriate as behavioural problems could be more prevalent in these populations, resulting in greater variability to analyze statistically. Plourde and colleagues (2018) had a larger sample than the present investigation and their results did not yield significance, but their population was not well-described and may have been similar to that of the present study in terms of athlete status. Their sample also appeared to be of a similar

socioeconomic status, with most parents holding a college or university degree. Thus, efforts should continue to be made to expand to populations of lower athletic and socioeconomic status.

Considering the criticisms outlined above about informant reports of adolescent behavioural adjustment, self-report forms may also want to be administered in addition to parent-report forms in future studies. Adolescent raters may be particularly better at reporting their own internalizing symptoms, including anxious and depressive thoughts and other unobservable behaviours (De Los Reyes & Kazdin, 2005).

This study also represents a building block for future research to expand on in terms of both concussion history and direction of causality. With a larger sample size, concussion history should be stratified such that recurrent concussions can be examined in relation to behaviour, as was the original aim of this study. Statistical methods such as multinomial logistic regression and receiver operating characteristic (ROC) curve analysis can be used to examine the specific behavioural profiles that differentiate two or more concussions from one concussion. As direction of causality cannot be inferred from these methods (i.e., concussion may cause behaviour problems, behavior problems may increase risk of concussion, or there may be a bidirectional effect), future studies should also seek to use longitudinal methods. For example, baseline BASC-3 scores could be used to predict the athletes who sustained a concussion over the course of a season, or even the athletes who are likely to have a more complicated recovery following concussion.

In conclusion, the present investigation represents the first step toward a more complete understanding of behavioural adjustment and concussion history. Although the

present study suggests that there is no relation between behavioural problems and concussion in elite child athletes, there is much room for improvement in study design and methodology. It is imperative that methodologically sound and generalizable studies continue to be conducted on the understudied population of child athletes to ensure proper concussion management among children.

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APPENDICES

Appendix A

The BASC-3 Parent Rating Scales (PRS)

The PRS takes approximately 10–20 minutes to complete and has three age-level forms: preschool (ages 2–5), child (ages 6–11), and adolescent (ages 12–21). As participants in the present study ranged from ages 10 through 17, the child and adolescent forms were used.

Each form contains descriptions of behaviours that the respondent rates on a four-point Likert scale ranging from 0 (*never*) to 3 (*almost always*). Note that a response of “*never*” indicates that the parent has never observed this behaviour or emotion in the child, not that the behaviour has never occurred outside the home or in contexts where the parent was not present (e.g., at school). Items are scored to form 9 clinical scales that assess the following areas of behaviour: aggression, anxiety, attention problems, atypicality, conduct problems, depression, hyperactivity, somatization, and withdrawal. Each item is unique to a scale; in other words, there are no items that contribute to more than one scale.

Norm-referenced *T*-scores are provided for each scale ($M = 50$, $SD = 10$). Gender- and age-specific norms will be used for this study. Across all clinical scales, high scores represent negative or undesirable behaviour or emotions that are generally problematic and cause impairments in functioning at home, at school, with peers, or in community settings. *T*-scores below 60 fall in the normal range; *T*-scores between 60 and 69 fall in the at-risk range, and *T*-scores above 69 fall in the clinical range.

Appendix B

Reliability and Validity Statistics for the BASC-3 Internalizing Problems and Externalizing Problems Composites

Reliability Statistics

Cronbach's α for the Internalizing Problems Composite and Externalizing Problems Composite of the child and adolescent PRS range from .93 to .97 (Reynolds & Kamphaus, 2015). Test-retest reliabilities for the child Internalizing Problems and Externalizing Problems Composites are good (corrected $r_s = .88$ and $.87$, respectively). Test-retest reliabilities for the adolescent Internalizing Problems and Externalizing Problems Composites are excellent (corrected $r_s = .93$ and $.93$, respectively).

Validity Statistics

Within the child form of the PRS, the Internalizing Problems Composite and the Externalizing Problems Composite correlate moderately ($r = .42$). Within the adolescent form of the PRS, they correlate strongly ($r = .64$). These correlations will be considered during the data cleaning process, as highly correlated predictors can lead to multicollinearity.

Appendix C

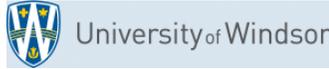
The Post-Concussion Symptom Scale (PCSS; ImPACT Technical Manual, 2011)

Symptom	Minor		Moderate		Severe	
Headache	1	2	3	4	5	6
Nausea	1	2	3	4	5	6
Vomiting	1	2	3	4	5	6
Balance Problems	1	2	3	4	5	6
Dizziness	1	2	3	4	5	6
Fatigue	1	2	3	4	5	6
Trouble Falling Asleep	1	2	3	4	5	6
Sleeping More Than Usual	1	2	3	4	5	6
Sleeping Less Than Usual	1	2	3	4	5	6
Drowsiness	1	2	3	4	5	6
Sensitivity to Light	1	2	3	4	5	6
Sensitivity to Noise	1	2	3	4	5	6
Irritability	1	2	3	4	5	6
Sadness	1	2	3	4	5	6
Nervousness	1	2	3	4	5	6
Feeling More Emotional	1	2	3	4	5	6
Numbness or Tingling	1	2	3	4	5	6
Feeling Slowed Down	1	2	3	4	5	6
Feeling Mentally "Foggy"	1	2	3	4	5	6
Difficulty Concentrating	1	2	3	4	5	6
Difficulty Remembering	1	2	3	4	5	6
Visual Problems	1	2	3	4	5	6

If subjects are not experiencing a symptom, they check a box indicating they are "not experiencing the symptom," and a score of 0 is assigned for that item.

Appendix D

Demographics Survey and Consent Form



SPFHA-SRCC Baseline Participant Form

0%

SRCC Baseline Consent Form

I agree to have my child undergo a baseline evaluation at the direction of the Sport-Related Concussion Centre (SRCC). I understand and agree that the results of this evaluation will be the sole property of the SRCC. I hereby WAIVE ANY AND ALL CLAIMS that I have or may in the future have against the University of Windsor AND RELEASE the University of Windsor, its officers, trustees, agents, and employees, from any and all liability for any loss, damage, expense or injury, including death, DUE TO ANY CAUSE WHATSOEVER, INCLUDING NEGLIGENCE, BREACH OF CONTRACT, OR BREACH OF ANY STATUTORY OR OTHER DUTY OF CARE ON THE PART OF SRCC.

I understand that the purpose of this evaluation is for sport concussion baseline testing and, if deemed appropriate by the SRCC staff, a post-concussion evaluation. Should my child be asked to undergo a post-concussion evaluation(s), I give permission for Supervising Clinical Neuropsychologist(s) to give information about my child's readiness to return to regular activities (including school and sports) to me, my team's head coach and/or trainer, as well as my child's physician. This information could be communicated through one or more of the following means: face-to-face conversation, secure email or fax, telephone, or mailed letter. The Supervising Clinical Neuropsychologist might also briefly discuss the basis for their impressions in one or more of these communications. I also consent to the coaches and/or trainer sharing their observations of my child's behavior, the nature of the injury, and my child's history with the Supervising Clinical Neuropsychologist(s).

Clinical and research evidence suggests that the measures selected for baseline and post-injury assessment are useful in forming an opinion about readiness to return to learn and return to play after sport-related concussion. Nonetheless, we do not claim that the measures included necessarily provide all the neuropsychological and other information that might be helpful in making such a decision or is it sufficient to provide a psychiatric diagnosis or a basis for academic, occupational, or rehabilitation planning or litigation. If your child has elevated symptoms at baseline testing, we may contact you for a follow-up interview where you will be asked some more questions to determine the reason for the elevation at baseline.

The baseline assessment will consist of the ImPACT computerized cognitive tasks, balance testing, a symptom survey, and parent-completed questionnaires that focus on the child's psychosocial and behavioral adjustment. The post-concussion assessment will consist of a clinical interview, the ImPACT computerized cognitive tasks, balance testing, and a symptom survey. Completion of the post-concussion assessment typically takes 60 minutes. The parent or legal guardian is responsible for paying the cost of the post-concussion assessment(s) at the time the assessment(s) takes place. Cost is \$150/hour, some or all of which you might recover through workplace benefits or extended health benefits. You will be provided with an invoice for this purpose.

Final return to play decisions will be made by me, the team's coach, and the team's trainer in consultation with the clinical neuropsychologist(s) and, if I request, my child's physician.

I understand that I may withdraw my consent to this evaluation and to the transfer of information at any time by means of a written letter. If I do not withdraw my consent, it will remain effective.

I understand that I have the right to receive a copy of this form upon my request.

Confidentiality

The services that you will receive are confidential, which means that:

1. We will not give information to anyone outside of the members of the SRCC about your child's evaluation except as otherwise provided in this document.
2. Only in exceptional circumstances where required by law will members of the SRCC disclose information about you to others without your consent. For example, disclosure is required by law in cases where there is a suspicion of child abuse or when a person poses a threat of serious injury to themselves or to others.

Teaching

By indicating below, I give the SRCC Faculty and Staff permission to use the information collected pursuant to this document for classroom teaching or public workshops. To maintain confidentiality, I understand that my name, as well as my child's name, date of birth, or any other information that might identify me or my family will not be included in any presentations. I understand that giving or withholding permission will in no way affect the services

that the SRCC is providing and that in the event that I give permission, I may rescind it at any time.

Research

Information collected pursuant to this document might be included in a group database that could be used for studies to better our understanding of sport-related concussion. Publications from this research would use de-identified data, with names, birthdates, and other personal information removed. No one can be identified in these publications, and your privacy and that of your family is completely protected. All research to come from this data must be approved by the University of Windsor Research Ethics Board. Researchers who obtain data with identifying information must maintain confidentiality. Researchers who use de-identified data will maintain anonymity of participant data.

Type Name of Parent/Guardian

Provide Signature (as best possible)

Clear

Next

Administrator



SPFHA-SRCC Baseline Participant Form

16%

Parent Demographics

Last name (parent)

Type here

First name (parent)

Type here

Primary Phone Number

Type here

Email Address

Type here

Relationship to Child

Mother

Father

Legal Guardian

Other, please specify...

Type here

Years of education completed (parent 1)

E.g., 12 = high school graduate; 14 = college diploma; 16 = university degree; 18 = Master's degree, etc.

Type here

Years of education completed (parent 2)

E.g., 12 = high school graduate; 14 = college diploma; 16 = university degree; 18 = Master's degree, etc.

Type here

[Back](#) [Next](#)

[Save and continue later](#)

[Administrator](#)



SPFHA-SRCC Baseline Participant Form

33%

Child Demographics

Child's First Name

Child's Last Name

(if different from parent)

Child's Date of Birth

Date

Child's Gender

- Male
- Female

Hockey Division

- Atom
- Peewee
- Bantam
- Midget / Jr

Child's Ethnic Background

- Aboriginal/First Nations
- Asian descent
- Black or African descent
- Hispanic/Latina
- Non-hispanic White/Caucasian
- Mixed/Bi-racial
- Other, please specify...

Type here

Child's Weight (lbs)

Required for balance testing

Type here

Child's Height (##")

Required for balance testing

Type here

[Back](#) [Next](#)

[Save and continue later](#)

[Administrator](#)



SPFHA-SRCC Baseline Participant Form

50%

Developmental & Medical History

Has your child ever been diagnosed with any of the following...?

Please select all that apply.

- Learning disorder
- Attention deficit hyperactivity disorder (ADHD)
- Depression
- Anxiety
- Epilepsy / seizure disorders
- Speech language disorder
- Autism spectrum disorder
- Oppositional defiant disorder
- Conduct disorder
- Vision problems
- Hearing problems
- Other, please specify...
- NONE APPLY

If so inclined, feel free to elaborate on your selections above.

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Save and continue later

Administrator

Page 4 1



SPFHA-SRCC Baseline Participant Form

66%

Concussion History

Many children experience injuries resulting in a hit to the head or jaw. These injuries can be sport-related (e.g., while skiing, snowboarding, biking, or skateboarding; from being body-checked; from being hit by equipment such as puck or ball), or non-sport-related (e.g., in a motor vehicle accident; as a result of fainting, falling, or slipping; while on the playground).

Has your child ever experienced an injury resulting in a hit to the head or jaw that caused confusion and/or one or more of the following symptoms: headache, nausea, vomiting, dizziness/balance problems, fatigue, trouble sleeping, drowsiness, sensitivity to light or noise, blurred vision, difficulty remembering, and difficulty concentrating?

Yes

No

Back

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Save and continue later

Administrator

SPFHA-SRCC Baseline Participant Form

83%

For each occurrence, please indicate the cause of the injury, the actual or estimated date each took place, and the associated symptoms and their length.

First Occurrence:

Cause of Injury	<input type="text" value="Type here"/>
Estimated Date	<input type="text" value="Type here"/>
Associated Symptoms	<input type="text" value="Type here"/>
How long did symptoms persist?	<input type="text" value="Type here"/>

Second Occurrence:

Cause of Injury	<input type="text" value="Type here"/>
Estimated Date	<input type="text" value="Type here"/>
Associated Symptoms	<input type="text" value="Type here"/>
How long did symptoms persist?	<input type="text" value="Type here"/>

Third Occurrence:

Cause of Injury	<input type="text" value="Type here"/>
Estimated Date	<input type="text" value="Type here"/>
Associated Symptoms	<input type="text" value="Type here"/>
How long did symptoms persist?	<input type="text" value="Type here"/>

Fourth Occurrence:

Cause of Injury	<input type="text" value="Type here"/>
Estimated Date	<input type="text" value="Type here"/>
Associated Symptoms	<input type="text" value="Type here"/>
How long did symptoms persist?	<input type="text" value="Type here"/>

Fifth Occurrence:

Cause of Injury	<input type="text" value="Type here"/>
Estimated Date	<input type="text" value="Type here"/>
Associated Symptoms	<input type="text" value="Type here"/>
How long did symptoms persist?	<input type="text" value="Type here"/>

[Back](#) [Submit](#)

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[Administrator](#)

Appendix E

Description and Operationalization of Covariates

Sex. Sex will be dummy coded and entered as a covariate if males and females are found to differ on the outcome variable (number of previous concussions). If it shows statistical significance, this indicates that the inclusion of sex adds predictive power to the model, and that the relationship between behaviour on the BASC-3 and concussion history differs between males and females.

Cognitive status. As there is no singular score representing the player's performance across all composites, the Visual Motor Speed Composite will be used to represent the player's cognitive status. The Visual Motor Speed Composite shows the best reliability compared to all other composite scores and demonstrates the least variability in ICC estimates across studies (Brett & Solomon, 2017). Additionally, this composite shows strong significant correlations with the ImPACT Verbal and Visual Memory Composites ($r_s = .88-.89$; Allen & Gfeller, 2011) and significant moderate correlations with the ImPACT Reaction Time and Impulse Control Composites ($r_s = .24-.58$; Allen & Gfeller, 2011). For these reasons, the Visual Motor Speed Composite will be used as the sole score representing cognitive status for this study. This variable will be entered as a covariate if it is found to correlate with the outcome variable. This data will be taken from the athlete's most recent baseline assessment, usually completed within a few days of parent completion of the BASC-3.

Post-Concussive Symptoms. The Total Symptoms Composite of the PCSS may be entered as a composite score to control for the effect of chronic post-concussive symptoms on the Somatization subscale of the Internalizing Symptoms Subscale. This composite scale measures the frequency and severity of current post-concussive symptoms for each player.

Duration since last concussion. Duration since last concussion (in days) may be entered as a covariate because those who have had a recent concussion may experience more behavioural problems, and those who have sustained multiple concussions are more likely to have a recent concussion compared to a player who has sustained one concussion. For athletes with zero previous concussion, the number entered will be the age in days of the youngest participant in the sample (4106 days). The reason for this is because covariates in a logistic regression must relate to all possible outcomes. In other words, entering the player's age in days is analogous to saying that they have never experienced a concussion in their lifetime, because a distant concussion (i.e., a larger value in terms of days since last concussion) should have a smaller effect on the model than a recent concussion (i.e., a smaller value).

Parental education. Given its association to both number of previous concussions and behavioural problems, parental education may be entered as a covariate. The number of years of education for both parents will be averaged into one variable to ensure that athletes who are being raised by single parents do not have missing data. Parental education will be entered as a predictor.

Age. Although age is commonly entered as a covariate in studies of concussion and behaviour, it will not be entered as a covariate in this model. The primary outcome

variables (the Internalizing Problems Index and Externalizing Problems Index of the BASC-3) are age-corrected, as the *T*-scores were generated using age-specific norms.

Appendix F

Assumptions of Logistic Regression

Categorical outcome variable. Whereas standard binomial logistic regression assumes a dichotomous outcome variable, multinomial logistic regression is an extension of the bivariate model where the outcome variable can have more than two levels (Hosmer & Lemeshow, 2000). The possible outcomes may be nominal, or they may be ordinal (Tabachnik & Fidell, 2007); for the present study, the number of previous concussions a player has sustained is an ordinal outcome variable.

Independence of observations and errors. Logistic regression assumes that each score and its residuals are statistically independent from the other scores. This assumption is often violated in experimental design with nested groups, as the observations may influence one another and may correlate. Additionally, it may be violated in designs that use repeated measures (Tabachnik & Fidell, 2007). In the present study, independence of observations was not a problem due to the research design. Lack of independence of observations can lead to over-dispersion, to be discussed later (A. Field, 2009).

Multivariate normality and linearity. Logistic regression does not assume normality, linearity, or homoscedasticity of variance, but it is important to note that multivariate normality and linearity among the predictors enhances statistical power (Tabachnik & Fidell, 2007). This is because linear combinations of predictors are used to form the exponent on which the prediction is based (Tabachnik & Fidell, 2007).

Univariate normality is necessary but not sufficient for multivariate normality. To assess for univariate normality, skew and kurtosis values were assessed for each predictor, and the histograms, boxplots, P-P plots and Q-Q plots were visually examined for normality. Skew and kurtosis values were divided by the standard error and a cutoff value of ± 1.96 was used (A. Field, 2013). The PCSS Total Symptoms Composite was the only variable to exceed this cutoff for skew with a value of 4.24, but as it theoretically makes sense for scores to cluster around zero, with individuals experiencing significant levels of post-concussive symptoms at baseline, a data transformation was not deemed necessary.

To assess for multivariate normality, Mahalanobis' distance was examined with a cut-off value of 101.879 determined using the Chi-square distribution with $k = 80$ (Tabachnik & Fidell, 2007). Cook's distance was also examined to assess for influential observations, using a cut-off of 1. No values exceeded this cut-off.

Linearity of the logit. Logistic regression assumes linearity of the logit (A. Field, 2009). In regression analyses, it is typically assumed that the outcome has a linear relationship with the predictors; however, in logistic regression the outcome is categorical or ordinal, so the logit of the outcome variable is used instead. It is assumed in linear regression that the logit is linearly related to the continuous predictor variables (Tabachnik & Fidell, 2007). This assumption was tested by adding terms to the logistic regression model composed of the interaction between a given predictor and its log transformation, where significance of the interaction term indicates violation of this assumption (A. Field, 2009; Tabachnik & Fidell, 2007). This assumption was satisfied for all predictors.

Absence of separation of groups. Complete separation of groups occurs when the data for the predictor variables do not overlap at given levels of the outcome variable (A. Field, 2009); for example, in the present study, if athletes with zero concussions fell in the Low-Normal to Normal range on the PCSS, athletes with one concussion fell in the Unusual range, and athletes with more than one concussion fell in the High range, there would be complete separation of groups. Separation of groups poses a problem when calculating the probability curves, as a maximum likelihood solution becomes impossible (Tabachnik & Fidell, 2007). This is observed in the output by extremely high parameter estimates and large standard errors (A. Field, 2009; Tabachnik & Fidell, 2007). Estimates also increase with succeeding iterations, or the statistics software may fail to converge on a solution entirely (Tabachnik & Fidell, 2007).

Should separation of groups occur, the recommended course of action is to collect more data; however, because the present dataset has been collected, the solution then becomes to exclude the offending predictor. In the case of the present study, failure to converge indicating separation of groups occurred when “Days Since Previous Concussion” was entered as a covariate, thus this predictor was omitted from all further analyses. Tabachnik and Fidell (2007) note that complete separation of groups is typically problematic when sample sizes are too small, as is likely the case with this dataset. This assumption remains satisfied so long as “Days Since Previous Concussion” is not used as a predictor.

Lack of incomplete information from the predictors. Incomplete information from the predictors becomes increasingly problematic as more predictors are added to the model (A. Field, 2009). This issue occurs when there is not enough data to support each combination of predictors; for example, in the present dataset, the statistics software will be unable to make predictions about concussions sustained with an elevated BASC-3 Internalizing Problems Index score, low BASC-3 Externalizing Problems Index score, high parental education, few concussive symptoms, and a long duration since their previous concussion if there are no athletes in the dataset who have that particular combination of predictor values. In other words, there is no way of estimating number of previous concussions sustained based on the other cases in the dataset, because no other cases provide that same combination of predictors as those values. Therefore, data should be collected from all combinations of predictor variables.

The assumption of incomplete information from the predictors can be assessed before analyses are conducted by calculating a contingency table (A. Field, 2009). Expected frequencies can be assessed in each cell to ensure that they are greater than 1. Field (2009) recommends that no more than 20% of cell frequencies are less than 5. When only the two primary predictors are considered, zero athletes fall in the range of having high BASC-3 Internalizing or Externalizing problems, indicating that no combination involving elevated BASC-3 Indexes is possible for athletes with a concussive history, whereas it is possible for athletes without a concussive history. Therefore this assumption is violated.

One solution for violations is to collect more data; however, the data has already been collected so another recommended solution is to remove one or more predictor variables. Because the researcher has already minimized the number of predictors entered into the model down to just the two primary predictors, this assumption will remain violated which will likely impact the likelihood of finding significant results.

Absence of over-dispersion. Over-dispersion occurs when the observed variance is larger than what would be expected from the logistic regression model (A. Field, 2009). Violations of this assumption can occur because of correlated observations (i.e., independence is violated), or variability in success probabilities which can lead to correlated observations (A. Field, 2009). Over-dispersion limits standard errors, which can cause tests to appear falsely significant and confidence intervals to appear falsely narrow (A. Field, 2009). Over-dispersion is present if the ratio of the goodness-of-fit statistic to its degrees of freedom is greater than 1 (A. Field, 2009). Over-dispersion is likely to be problematic if the ratio approaches or exceeds 2 (A. Field, 2009). This assumption was met for the present sample.

Absence of multicollinearity. Multicollinearity occurs when predictor variables are highly correlated with one another. Singularity occurs when predictor variables are so highly correlated with one another that they likely represent the same construct. Multicollinearity in the dataset is identified by exceedingly large standard errors for parameter estimates (Tabachnik & Fidell, 2007). Multicollinearity can be tested by running the model as a standard linear regression analysis and examining the variance inflation factor and tolerance (A. Field, 2013). In the presence of multicollinearity, the recommended solution is to remove one or more redundant predictors. Alternatively, two highly correlated predictors can be combined into one (Tabachnik & Fidell, 2007). Neither of the primary predictor variables were correlated with one another ($r = .16, p > .05$), thus multicollinearity was not likely to be a problem with these variables. Given that time since last concussion was entered as age in days for those that had not had a concussion (see Appendix E), this variable was significantly correlated with age ($r = .99, p < .001$); however as it was already determined that there was a failure of convergence when days since last concussion is entered as a predictor, this is not a concern for multicollinearity as this predictor cannot be used in the model. The ImPACT Visual Motor Speed Composite and age were significantly correlated ($r = .33, p = .04$), as were the PCSS Total Symptoms Composite and sex (coded such that 1 = male and 2 = female; $r = .50, p = .001$), but both of these correlations were judged to be low enough so as not to constitute multicollinearity.

Further collinearity diagnostics were examined by running the logistic regression model with only the two primary predictors as a linear regression and examining the Variance Inflation Factor (VIF) and tolerance statistics. Tolerance values less than 0.1 and VIF values greater than 10 are indicative of collinearity (A. Field, 2013); neither predictor exceeded these cut-offs. In sum, the assumption of multicollinearity was met.

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