THE ASSOCIATION BETWEEN THE BUFFALO CONCUSSION TREADMILL TEST AND TIME TO RECOVERY IN ADOLESCENT ATHLETES: A RETROSPECTIVE COHORT STUDY

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ABSTRACT

The Buffalo Concussion Treadmill Test (BCTT) is a graded aerobic test used to assesses exercise tolerance following concussion. The purpose of this study was to examine the association between the result of a first attempt BCTT performed 10-21 days after injury and recovery in a sample of Canadian adolescents with sport related concussion (SRC). Data from 855 adolescents was extracted between January 2016 and January 2019 from the Complete Concussion Management database. The BCTT was categorized as “pass” or “fail” based on symptom exacerbation with testing. After adjusting for participant, injury and assessment characteristics, failing a first BCTT was associated with 13 increased days to recovery (ß=13.173, 95% CI= 8.977, 17.369) compared to a pass result. The BCTT, participant, injury and assessment characteristics explained 11.8% variation in recovery (R2= 0.118). When assessing for time to recovery in SRC clinicians should use a range of variables including the BCTT.

ACKNOWLEDGMENTS

About 3 years ago I was a young chiropractor looking to get my foot into research. I had applied to over 5 different institutions across Canada only to be rejected. The next year, I pulled out all the stops, by networking with supervisors, applying for NSERC funding and taking extra undergraduate courses. But again, I was rejected.

It was soon after the second round of rejections that I was standing on the corner of Yonge and Dundas in Toronto where I ran into Dr. Tamim. She had taught an Epidemiology course which I took to increase my GPA for funding and applications. On that street corner we had a quick chat and she agreed to be my supervisor. She had said “yes” and subsequently York University had also said “yes”.

I want to acknowledge all the professors who said “yes”, held doors open, and pushed me forward. They are Dr. Scott Howitt at the Canadian Memorial Chiropractic College, Dr. Cesar Hincapie at the University of Zurich, Dr. Nazanin Virji-Babul at the University of British Columbia, Dr. Anne Hunt at Holland Bloorview Kids Rehabilitation Hospital and Dr. Alison Macpherson at York University. Most of all, I would like to thank Dr. Tamim for giving me the opportunity to learn from her. I hope one day we have the opportunity to work together again as collaborators.

Thank you to my lab mates who have filled these two years with laughter and my girlfriend who constantly puts up with my lack of time. Finally, thank you to my parents who immigrated here

from Africa, who sacrificed their opportunity for education in order to work, so that their son may one day have his.

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CHAPTER 1: EXPANDED INTRODUCTION

Sport related concussion (SRC) is a traumatic brain injury induced by a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head.[1] Unlike more severe forms of brain injury such as subdural/epidural hematoma and stroke which show macroscopic neural damage, a concussion is instead defined as a functional or microstructural injury.[1] This refers to injury related changes which are not readily detectible on a computerized tomography (CT) scan or conventional magnetic resonance imaging (MRI).[1] The pathophysiology of concussion has been described as a neurometabolic cascade of events which includes bioenergetic challenges, cytoskeletal and axonal alterations, impairments in neurotransmission and vulnerability to delayed cell death and chronic dysfunction.[2] These changes manifest themselves clinically as symptoms in somatic (headache, nausea, neck pain, dizziness), cognitive (forgetfulness, inattention, feeling slowed down) and emotional domains (irritability, increased emotionality).[1]

A 2016 report by the Canadian Institute for Health Information (CIHI) found a 78 percent increase in concussion emergency department visits among those between 0-9 years of age and a 45 percent increase among those aged 10-17 over a 5-year span.[3] Approximately 70 percent of these adolescent concussions are sport related with the majority coming from hockey and football.[4] The Adolescent SRC population is important to study for two reasons. First, the high rates of concussion within the adolescent population is troubling as the developing brain is more vulnerable to hypoxia and ischemia following concussion and requires more time to recover following injury when compared to adult counterparts.[5] This has been confirmed in diffusion tensor MRI imaging studies, which show white mater damage following adolescent concussion long after clinical recovery has been achieved.[6] Second, adolescents who are returning to sport who do so too quickly place themselves at risk for subsequent concussion, longstanding concussion symptoms and life threating conditions such as second impact syndrome.[7]

Although most patients recover symptomatically from an acute concussion within 10-14 days, 10-25 percent of patients with concussion develop longstanding concussion symptoms.[8] Longstanding symptoms have in the past been termed Post-Concussion Syndrome (PCS). PCS is diagnosed according to the International Classification of Diseases (ICD)-10 or Diagnostic and Statistical Manual of Mental Disorders (DSM)-4 criteria.[9,10] To meet the ICD-10 diagnostic criteria of PCS a patient must sustain a head injury and develop at least three of eight specific symptoms which last four weeks or longer. These symptoms include headache, dizziness, fatigue, irritability, sleep problems, concentration problems, memory problems and problems tolerating stress.[9] In contrast, The DSM 4 criteria requires immediate symptom onset, persistence of concussion-like symptoms for at least 3 months and objective evidence of attention and/or memory deficit for a diagnosis of PCS[10]. More recently, the term persistent-post concussion symptoms is used in the literature to bridge the gap between PCS definitions in the ICD-10 and DSM-4. Persistent-post concussion symptoms are defined by adults who take longer than two weeks to achieve recovery or children and adolescents who take longer than 4 weeks to achieve recovery following concussion.[1]

Persistent post-concussion symptoms are a challenge to diagnose, treat and infer prognosis upon. This is partly due to the pathophysiology of this condition being complex, multifactorial, and still up for debate. Diagnostic trajectories for persistent-post concussion symptoms have been outlined in the literature to help guide clinicians in assessment and treatment approaches. These trajectories include physiological post-concussion disorder (PCD), vestibulo-ocular PCD and/or cervicogenic PCD.[11] The clinical trajectory of physiological PCD attributes longstanding concussion symptoms to persistence of the biochemical, autonomic and cerebrovascular alterations that are characterized in acute concussion. This can be seen in alterations of cerebral blood flow and heart rate at rest and with exercise in adolescents and adults with persistent post-concussion symptoms.[12,13] This abnormal control of cerebral blood flow control is suggestive of imbalances of the Autonomic Nervous System (ANS). The vestibulo-ocular trajectory of PCD attributes longstanding concussion symptoms to dysfunction of the central and peripheral components of the vestubulo-ocular sub-system,[11] while the cervicogenic trajectory attributes these changes to dysfunction of the cervical spine.[11] Out of the three different causes of persistent post-concussion symptoms it is the physiological trajectory which primarily encompasses central changes following concussion.[14] Therefore, when looking for a test which can be used to guide clinical decision making at the acute and subacute stages of a concussion, it is likely that the assessments which encompass the physiological trajectory will prove useful. The Buffalo Concussion Treadmill Test (BCTT) is one which stands out due to its ease of use, it's safety in an acute concussion sample[15] and its high reliability in assessing for concussion.[16] Limited research exists examining the relationship between the BCTT and recovery following SRC. In addition, no current study exists which uses a multivariable model to control for potential confounders in this association. The purpose of this thesis is to assess the association between the crude "pass" or "fail" result of a participants first attempt BCTT, performed between 10 and 21 days after injury, and days from injury to recovery in a sample of Canadian adolescents aged 17 or under with SRC in a multi-disciplinary clinical setting. We hypothesize that participants who fail their first attempt BCTT, performed between 10-21 days following injury, will show an increased amount of days from injury to recovery when compared to those who passed their first attempt.

CHAPTER 2: COMPLETE MANUSCRIPT

ABSTRACT

Background

The Buffalo Concussion Treadmill Test (BCTT) is a graded aerobic test used to assess exercise intolerance following concussion. The purpose of this study was to examine the association between the result of a first attempt BCTT performed between 10 and 21 days after injury and days from injury to recovery in a sample of Canadian adolescents with sport related concussion (SRC) in a multi-disciplinary clinical setting.

Methods

Data from 855 (480 males and 375 females) adolescents were extracted between January 2016 and January 2019 from the clinical database of Complete Concussion Management Inc. Participants received a diagnosis of SRC from a regulated healthcare professional, performed their first BCTT between 10 and 21 days after injury and scored ≥ 7 on the Post-Concussion Symptom Scale (PCSS) at intake. Participants with findings not consistent with concussion, currently diagnosed with learning/anxiety/depressive disorder or with history of >3 concussions were excluded. The BCTT was categorized as "pass" or "fail" based on presence of symptom exacerbation with testing. Recovery was defined by passing a BCTT, completion of a stepwise return-to-play process, completion of the Gapski-Goodman exertion test, normalization of symptom severity score and assessment by a regulated healthcare professional. Hierarchal linear regression was used to assess the association between the BCTT result and days from injury to recovery adjusting for participant characteristics (age, sex, previous history of concussion), injury characteristics (loss of

consciousness at injury, presence of amnesia at injury, sport mechanism of injury, symptom severity score at time of intake) and assessment characteristics (days from injury to initial clinical intake, days from injury to first BCTT).

Results

After adjustment for participant, injury and assessment characteristics, failing a first attempt BCTT was significantly associated with 13 increased days to recovery when compared to a pass result (ß=13.173, 95% CI=8.977, 17.369, R^2=0.118). This model explained a total of 11.8% variation in recovery, 4% of which was contributed from the BCTT result alone (R^2= 0.118, R^2 change= 0.04).

Conclusion

First attempt BCTT was significantly associated with increased time to recovery. This significance of the association was retained with the addition of participant, injury and assessment characteristics. When communication prognosis to patients and families with SRC, clinicians should use a range of variables, including the BCTT.

INTRODUCTION

Concussion is defined as a brain injury that is induced by an impulsive biomechanical force transferring from the body to the brain.[1] Although most patients recover symptomatically from an acute concussion within 7-10 days, approximately 10%-25% develop persistent post-concussion symptoms.[8,17] In children and adolescents this is described as symptoms lasting over 30 days.[1] Symptom severity, assessed by concussion specific checklists, in the acute and subacute phase following a concussion is considered to be the most accurate predictor of time to recovery.[18,19] In addition, patient characteristics such as age, sex, previous history of concussion, learning disability, history of migraines and previous psychological illness are also known risk factors for prolonged recovery after concussion.[20,21,22,23]

Persistent post-concussion symptoms can be attributed to longstanding autonomic nervous system (ANS) disruption following concussion.[24] This manifests in impairments to cardiac rhythm and cerebral blood flow control both at a resting state and with exercise.[25] The Buffalo Concussion Treadmill Test (BCTT) is a graded aerobic test that can safely assess level of exercise intolerance even in acute concussion.[15,26]. Participants who achieve maximal level of perceived exertion without symptom execration on the BCTT are considered physiologically recovered from concussion and provided a passed result.[26] More recently, the BCTT has proved useful in assessing patient prognosis following concussion. A randomized control trial which assessed safety of the BCTT in an acute concussion sample randomized 54 adolescent participants to either a group which performed the BCTT or to a control group. When analysis was performed on participants in the BCTT group, heart rate threshold (HRt), defined as the average heart rate on the final minute of the BCTT was significantly associated with days to recovery (R^2=0.2982, p=0.0032).[15] A retrospective cohort study further exhibited Δ HR (the difference between resting heart rate and HRt) captured from the BCTT was significantly associated with duration of clinical recovery in a sample of 27 adolescents prescribed rest (R^2=0.126, p=0.012) following concussion.[27] In an attempt to further assess the BCTT's relationship with concussion recovery and understand how the use of a crude "pass" or "fail" BCTT outcome may impact this effect we aimed to assess the association between a failed first attempt BCTT conducted between 10- and 21-days following sport related concussion (SRC) and days from injury to recovery in a sample of Canadian adolescents under the age of 18.

MATERIALS AND METHODS

Study Design

This study retrospectively analyzed Canadian data collected by private clinics of the Complete Concussion Management Inc. (CCMI) network between January 2016 and January 2019.[28] Within this clinical setting, patients were either referred or diagnosed at CCMI clinics with a sport related concussion (SRC). Diagnosis of SRC at CCMI was provided by a regulated healthcare professional (medical doctor, physiotherapist, chiropractor) according to the international Concussion in Sport Group (CISG) criteria.[1] No record was kept as to which healthcare professional provided this diagnosis. After diagnosis, patients progressed through a concussion management strategy which included return to learn and play steps according to the CISG criteria.[1] In instances where recovery did not progress as expected (i.e., still symptomatic beyond 10-14 days post injury), patient-specific rehabilitation programs were initiated and may have included cervical spine therapy, vestibular therapy, oculomotor therapy, balance re-training or sub-symptomatic aerobic training and/or referral for medical and/or psychological intervention. This is done in accordance with the respective domain of symptoms and the clinical experience of the attending practitioner. Participant consent is obtained from the athlete or their parent/guardian to allow for de-identified health data to be extracted from this database and used for research purposes.[29] This study was approved by the research ethics board of York University in Toronto, Canada.

Participants

Male and female adolescents with SRC who performed their first attempt, since time of injury, BCTT between 10-21 days after injury between January 2016 to January 2019 were included in this study. Participants within CCMI clinics perform their first BCTT when asymptomatic at rest or if symptomatic at 10 days or later. Therefore, the 10-21-day timeline was chosen to include participants mostly symptomatic at rest but not yet determined to be a persistent case according to CISG criteria.[1] Participants were excluded if they presented with (1) findings not consistent with diagnosis of concussion, including focal neurological deficit, skull fracture, abnormalities visualized by CT, micro-hemorrhaging visualized by MRI; (2) patients unable to safely walk on treadmill due to orthopedic injury or vestibular deficit; (3) patients with current diagnosis and/or under treatment for ADHD, learning disorder, depression, anxiety, autism, sleep disorder or history of more than 3 prior concussions (these factors are associated with delayed recovery);[20,21,22,23] (4) patients who scored <7 on concussion symptom severity at initial assessment (as normally developing adolescents may present with concussion-like symptoms).[30] Participants without a recorded date of injury and/or date of recovery were not extracted from the CCMI database as the outcome of “days from injury to recovery” could not be produced without these dates.

BCTT Test

Before BCTT test administration, baseline level of concussion symptoms on a Visual Analog Scale (VAS) from 0-10 and resting heart rate measurements was taken.[31] Participants were then asked to walk on a treadmill starting at a speed of 3.2 mph starting at 0 degrees incline. Treadmill incline was increased by 1 degree each minute for the first 15 minutes of the BCTT. Following max incline, the treadmill speed was increased by 0.4 mph every minute. Heart rate, Borg Rating of Perceived Exertion (RPE) and VAS was recorded at each minute of the BCTT until concussion symptom exacerbation or voluntary exhaustion was achieved.[31,32] Symptom exacerbation was defined as an increased of 3 or more points from VAS taken at baseline. Voluntary exhaustion was defined as a score of 17 to 20 on the RPE Scale.[32] Participants able to exercise to full level of perceived exertion without concussion symptom exacerbation were deemed to have passed the BCTT.[26] Those unable to exercise to a full level of perceived exertion due to concussion symptom exacerbation were defined as failing the BCTT.[26] For the present study, the first attempt BCTT, performed between 10- and 21-days following injury was categorized as passed or failed.

Days from injury to recovery

The outcome, days from injury to recovery, was analyzed as a continuous variable. This variable was created by calculating the difference between date of injury and date the patient was provided medical clearance and discharged. Recovery was defined as normalization of symptom severity score, a passed BCTT, successful completion of the Gapski-Goodman physical exertion test for concussion,[33] assessment by regulated healthcare professional (medical doctor, physiotherapist, chiropractor) and full completion of stepwise return to play process outlined by the Berlin concussion consensus statement.[1]

Covariates

Participant specific characteristics included sex, age at injury, and history of previous concussions. Injury specific characteristics included presence of loss of consciousness (LOC) at time of injury, presence and type of amnesia at time of injury, sport mechanism of injury categorized by similarity in incidence rates of concussion within each sport,[34] symptom severity score completed at initial visit which consists of a 22-item checklist used to evaluate the presence of concussion charecteristics.[1] Sport mechanism of injury was analyzed due the potential for differing recovery time between sports.[20] Assessment specific characteristics included days from injury to initial assessment at CCMI and days from injury to first BCTT at CCMI. Finally, treatment specific variables included number of total SOAP (Subjective, Objective, Assessment, Plan) notes documented by treating practitioner, number of SOAP notes which included visual or vestibular therapy and the total number of BCTT's performed. All data of study variables was collected from the CCMI database by the attending regulated healthcare practitioner at time of intake.

Statistical Analysis

Data analysis was performed using IBM Statistical Package for the Social Sciences (SPSS) and alpha level was set as 0.05. Simple linear regression was used to assess the relationships between each of the independent variables with the outcome variable at the bivariate level. Hierarchal linear regression analysis was performed, and 4 different multiple linear regression models were conducted. Model 1 included participant characteristics only, Model 2 added both injury and assessment characteristics to model 1. Model 3 included variables in model 1, model 2 and the BCTT result. Model 4 included variables in model 1, model 2, treatment variables and the BCTT result. Descriptive statistics of the sample used raw numbers, percentages, means and standard deviations. Unstandardized beta coefficients, 95% Confidence Intervals (CI) and R^2 were reported for the simple and multiple linear regression models.

RESULTS

A total of 1,279 patients were extracted from the CCMI database between January 2016 and January 2019. After applying the exclusion criteria, the final sample consisted of 855 patients. Details on data extraction and excluded cases can be found on Figure 1. The final sample was primarily male (n=480) with an average age of 14.05 (SD=2.106) years and a median age of 14.00 (IQR=13-16). The youngest participant included in this sample was 6 years old at time of SRC. The majority of participants had no concussion history (n=475) and did not present with LOC (n=804) or amnesia following injury (n=710). Hockey was the most common sport of injury occurrence (n=394). The average PCSS score at time of injury was 30.54 (SD=18.366). Patients received an initial assessment an average of 5.30 (SD=3.228) days after injury and participated in their first BCTT on average 14.04 (SD=3.228) days following concussion. Participants on average had 3.48 (SD=2.075) SOAP notes on file corresponding to this specific concussive event. Average days from injury to recovery for our sample was 32.16 (SD=25.831) days and median days to recovery was 25 days (IQR=19-33). Figure 2 displays the overall distribution of the outcome variable of time to recovery. Patients who failed a first attempt BCTT took on average 15.05 more days to recovery (unadjusted ß =15.05, 95%CI= 10.832, 19.267) when compared to those who passed their first attempt. Table 1 summarizes the baseline patient characteristics and bivariate analysis.

Table 2 shows the results of the hierarchical linear regression analysis performed. Model 1 included participant characteristics and explained 2.5% variation in days to recovery following concussion (R^2=0.025). Model 2 included participant, injury specific and assessment specific characteristics which explained 7.8% variation in days to recovery (R^2=0.078). Model 3 added the BCTT to model 2 and together explained 11.8% variation in days to recovery (R^2=0.118, R^2 change=0.04). After adjusting for participant, injury and assessment characteristics, failing a first attempt BCTT was associated with a 13.173 (ß= 13.173, 95%CI= 8.977, 17.369) increase in days to recovery when compared to pass result. History of previous concussion (ß=2.913, 95%CI=.846, 4.979) was shown to be associated with increased days to recovery as was sport mechanism of injury in volleyball/cheerleading/skiing when compared to the reference category of hockey (ß= 8.757, 95%CI = 2.387, 15.127). Days from injury to first BCTT was also significantly associated with delayed recovery time (ß=1.298, 95%CI=.741, 1.856) within model 3.

Model 4 added treatment specific variables to model 3. This combined model explained 18% of the variation in recovery (R^2= 0.18). A failed first attempt BCTT was significantly associated with an increase of 6.588 days to recovery (ß=6.588, 95%CI=1.254, 11.92) when compared to those who passed after adjusting for participant, injury, assessment and treatment variables.

DISCUSSION

This retrospective cohort study is the first to assess the relationship between a first attempt crude "pass" or "fail" BCTT result and days to recovery. Increased understanding of this relationship can lead to greater clinical utility of the BCTT during assessment of SRC, increased anticipatory guidance in determining return to play and return to learn timelines and wider use of a first attempt BCTT result as variable for adjustment for in future studies.

This study showed a failed result on a first attempt BCTT, when performed between 10 and 21 days after injury, was associated with an average increase of 15 days to recovery. The BCTT alone explained a total of 5.4% of the variation in recovery at the bivariate level (ß=15.05, 95%CI= 10.832, 19.267, R^2=0.054). After adjusting for participant characteristics, injury and assessment specific characteristics a failed BCTT was associated with an average increase of 13 days to recovery when compared to a pass result (ß=13.173, 95%CI=8.977, 17.369). This model explained a total of 11.8% variation in recovery, 4% of which was contributed from the BCTT result alone (R^2= 0.118, R^2 change= 0.04). Earlier studies which use heart rate specific BCTT results also show associations with time to recovery in adolescent SRC.[15,27] For example, Haider et al. captured the BCTT result as Δ HR in a sample of 130 adolescents < 10 days after injury. Participants were then assigned to either a regiment of rest, light stretching or aerobic activity for 4 weeks. A participants Δ HR measured during a BCTT was shown to explain 22.8% variation within the rest group (R^2=0.228, p=0.012), 12.6% variation in the light stretch group (R^2=0.126, p=0.011) and 5.9% variation in recovery within the aerobic activity group (R^2=0.059, p=0.084).[27] Leddy et. al. examined the relationship between HRt and days to recovery in a sample of 27 adolescents who performed the BCTT 1-10 days after injury. After a 14 day follow up, HRt was shown to be significantly associated with days to recovery and explained 29.82% variation in days to recovery (R^2=0.2982, p=0.0032).[15]

The reduced percent variation this study reports in contrast to previous work which also assesses the relationship between the BCTT and recovery[15,27] may be due to (1) the use of a crude pass or fail BCTT result which does not take into account individual heart rate; (2) the use of a sub-acute concussion sample which reflects less neurometabolic and axonal dysfunction when compared to participants at an acute phase of concussion (<10 days);[2] (3) a more robust definition of recovery which includes completion of a stepwise return to play process,[1] completion the Gapski-Goodman exertion test[33] and final assessment of regulated healthcare professional.

Sex was significantly associated with time to recovery, with females showing increased recovery time when compared to males in model 1. This relationship was no longer significant after adjustment in model 3. Model 3 showed participants with a prior history of concussion took significantly longer to recover when compared to participants with no history. A systematic review evaluating factors associated with clinical recovery following SRC reported no relationship between prior concussion history and recovery time.[18] However, this relationship has been shown in large-scale observational studies.[20,35] Although the literature remains quite mixed, previous history of concussion has been associated with increased symptom reporting in athletes[36] and is a risk factor for sustaining a subsequent concussion.[37] As a result, knowledge of a previous concussion may result in more conservative clinical decision making in an athletic population. Participants injured in the volleyball, cheerleading, skiing group took significantly longer to recover when compared to participants injured in hockey. A systematic review and meta-analysis of concussion incidence in youth sports reported rugby, American football and hockey have the highest rates of concussion at 4.18, 1.20 and 0.53 per 1000 athlete exposures.[34] The lowest incidence rates were shown to occur in volleyball, baseball and cheerleading at 0.03, 0.06 and 0.07 per 1000 athlete exposures respectively.[34] It is possible that low incidence of concussion creates a blinding effect whereby participants are unaware of the signs and symptoms leading to poorer overall management of the injury. This in turn can lead to poorer prognostic outcomes.[38] For example, concussions within the sport of cheerleading most frequently occur in practice were athletic therapists may not be available to screen for injuries.[39] An increased number of days from injury to first BCTT was also shown to be significantly associated with increased days to recovery in model 3. It is important to note that exercise has a dose dependant response on patients with concussion. Excessive or above threshold exercise can increase time to recovery, while minimal or no exercise can also have detrimental effects.[40] It is recommended that after 48 hours of rest patients begin to gradually increase cognitive and physical activity in a symptom limited capacity.[1] When performed at sub-symptomatic levels exercise even at the acute stage of a concussion has been shown to reduce time to recovery.[41] An increase in days between injury and first attempt BCTT may indicate delayed use of therapeutic exercise which can increase overall recovery time. Finally, number of total SOAP notes (ß=3.147, 95%CI=2.191, 4.103) and number of total BCTT's performed (ß=1.879, 95%CI=-2.509, 6.266) was shown to be significantly associated with days from injury to recovery after adjusting for all covariates. This relationship is unsurprising as patients who required more care are likely to take longer to receive recovery clearance by their attending practitioners.

Limitations

Selection bias exists due to the homogenous nature of participants utilizing multi-discipline community clinics for concussion care. Only patient data with definite dates of injury and recovery were extracted. As a result, participants lost to follow up or without complete recovery were not captured. Information bias may also exist in the unlikely possibility participants performed a prior BCTT before attending a CCMI clinic and from the differing practitioners diagnosing concussion (medical doctor, physiotherapist, chiropractor). This was minimized by excluding patients with a PCSS score of < 7 and following the CISG diagnostic criteria for concussion.[1] However, Parachute Canada Concussion in Sport guidelines outlines this diagnosis can be provided by only medical doctors and nurse practitioners.[42] Participants in this sample received concussion care which may improve recovery time following concussion and presents as confounding bias. Knowledge of passed or failed BCTT exposure result may also influence the outcome of days to recovery as practitioners were unblinded to this result. It is possible that the for-profit nature of multidisciplinary clinics may result in unnecessary follow-up and repeat care. The average number of patient visits recorded within our sample was 3.48 which is clinically reasonable for a concussion. Finally, patient heart-rate data for each first attempt BCTT was extracted from the CCMI database but was unanalyzed.

CONCLUSION

This study found a failed first attempt BCTT performed between 10-21 days after injury was significantly associated with increased days to recovery when compared to a passed result after adjusting for patient, injury and assessment characteristics. In an event where heart rate measurement equipment is unavailable, the use of a crude BCTT result might still prove helpful in the clinical assessment of days to recovery following adolescent SRC. Future studies which look at concussion recovery time should use the first attempt BCTT result as a covariate for adjustment if available. Currently this relationship has only been examined in an adolescent sample with SRC and should also be examined in other age groups with different mechanisms of injury.

FIGURE 1: DATA EXTRACTION AND PARTICIPANT EXCLUSION FLOWCHART

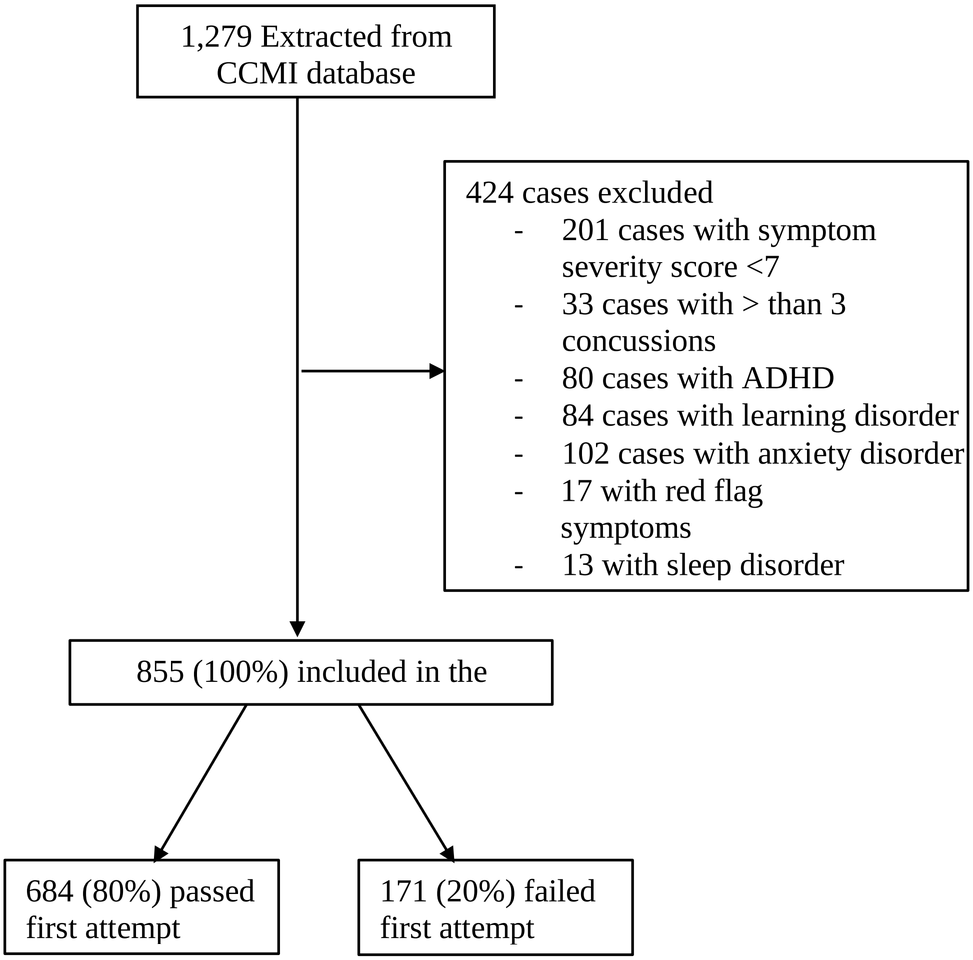


Table 1. Sample characteristics and relationship with outcome of days from injury to recovery using simple linear regression.

	N (%)	Mean (SD)	Unstandardized ß (SE)	95% CI	R Square
BCTT Test Result					
Pass	684 (80%)		Ref.		
Fail	171 (20%)		15.05 (2.149)	**10.832, 19.267**	0.054
Participant Characteristics					
Age (Years)*					
≤ 9 Years	27 (3.2%)				
10 to 11 Years	83 (9.7%)				
12 to 13 Years	188 (22.0%)				
14 to 15 Years	330 (38.6%)				
16 to 17 Years	227 (26.5%)	14.05 (2.106)	1.282 (0.418)	**0.463, 2.102**	0.011
Sex					
Male	480 (56.1%)		Ref.		
Female	375 (43.9%)		3.758 (1.777)	**.271, 7.245**	0.005
Previous Concussions*					
0	475 (55.6%)				
1	260 (30.4%)				
2	88 (10.3%)				
3	32 (3.7%)	.62 (.816)	3.236 (1.078)	**1.121, 5.352**	0.01
Injury Specific Variables					
Loss of Consciousness					
No	804 (94%)		Ref.		
Yes	51 (6%)		-4.825 (3.728)	-12.143, 2.493	0.002
Type of Amnesia					
None	710 (83.0%)		Ref.		
Anterograde	75 (8.8%)		1.999 (3.138)	-4.16, 8.158	
Retrograde	70 (8.2%)		2.797 (3.238)	-3.558, 9.151	0.001
Sport Injured					
Hockey	394 (46.1%)		Ref.		
Football/Rugby	128 (15%)		1.083 (2.614)	-4.048, 6.214	
Soccer/Basketball	152 (17.8%)		2.978 (2.453)	-1.837, 7.793	
Volleyball/Cheer/Skiing	73 (8.5%)		11.653 (3.274)	**5.227, 18.079**	
Other	108 (12.6%)		1.477 (2.791)	-4.001, 6.954	0.015
Symptom Severity Score*					
≤ 21	331 (38.7%)				
22 to 37	275 (32.2%)				
38 to 55	163 (19.1%)				
>55	86 (10.1%)	30.54 (18.366)	1.81 (0.48)	**0.088, 0.275**	0.017
Assessment Specific Variables					
Days from Injury to Assessment*					
≤ 7	648 (75.8%)				
8 to 14	185 (21.6%)				
≥15	22 (2.6%)	5.30 (3.827)	0.464 (0.231)	**0.012, 0.917**	0.005
Days from Injury to 1st BCTT*					
10 to 15	568 (66.4%)				
16 to 21	287 (33.6%)	14.04 (3.228)	1.508 (0.269)	**0.979, 2.036**	0.035
Treatment Specific Variables					
Number of SOAP Notes Total*					
1 to 3	511 (59.8%)				
≥ 4	344 (40.2%)	3.48 (2.075)	4.284 (0.4)	**3.498, 5.069**	0.118
Number of SOAP's with Vis/Vest*					
0 to 1	723 (84.6%)				
≥ 2	132 (15.4%)	.63 (1.350)	3.892 (0.641)	**2.633, 5.15**	0.041
Number of BCTT Performed*					
1 to 2	828 (96.8%)				
3 to 5	27 (3.2%)	1.22 (.506)	12.014 (1.699)	**8.68, 15.348**	0.055

*Analyzed as continuous variable in linear regression analysis

Table 2. Model Specifications for the impact of the BCTT on days from injury to recovery with sequential adjustment for specific of covariates

	Model 1. Participant characteristics		Model 2. Model 1 + Injury + Assessment		Model 3. Model 2 + BCTT Result		Model 4. Model 3 + Treatment	
	Unstandardized ß (SE)	95% CI	Unstandardized ß (SE)	95% CI	Unstandardized ß (SE)	95% CI	Unstandardized ß (SE)	95% CI
Participant Characteristics								
Age (years)	1.051 (0.421)	**.225, 1.877**	0.749 (0.425)	-0.84, 1.583	0.723 (0.416)	-.093, 1.538	0.512 (0.403)	-.279, 1.302
Sex								
Male	Ref.		Ref.		Ref.		Ref.	
Female	4.027 (1.777)	**.538, 7.515**	1.522 (1.905)	-2.217, 5.262	1.127 (1.866)	-2.535, 4.789	0.295 (1.809)	-3.256, 3.845
Previous concussion	3.117 (1.09)	**.977, 5.256**	3.397 (1.073)	**1.292, 5.503**	2.913 (1.053)	**.846, 4.979**	2.88 (1.019)	**.881, 4.880**
Injury Specific Characteristics								
Loss of consciousness (yes/no)			-5.205 (3.756)	-12.577, 2.168	-5.27 (3.676)	-12.486, 1.946	-5.778 (3.552)	-12.75, 1.195
Presence and Type of Amnesia								
None Reported			Ref.		Ref.		Ref.	
Anterograde Amnesia			2.491 (3.102)	-3.599, 8.580	2.707 (3.037)	-3.253, 8.667	3.464 (2.935)	-2.298, 9.225
Retrograde Amnesia			2.858 (3.257)	3.535, 9.251	2.879 (3.188)	-3.377, 9.136	4.408 (3.085)	-1.647, 10.464
Sport Injured								
Hockey			Ref.		Ref.		Ref.	
Football/Rugby			0.015 (2.585)	-5.058, 5.088	-0.235 (2.53)	-5.2, 4.731	0.17 (2.446)	-4.632, 4.971
Soccer/Basketball			2.192 (2.471)	-2.658, 7.043	0.769 (2.43)	-4.00, 5.537	0.976 (2.351)	-3.639, 5.590
Volleyball/Cheerleading/Skiing			10.761 (3.299)	**4.285, 17.237**	8.757 (3.245)	**2.387, 15.127**	7.773 (3.139)	**1.612, 13.933**
Other			1.242 (2.809)	-4.271, 6.754	0.428 (2.752)	-4.973, 5.830	0.948 (2.669)	-4.292, 6.188
Symptom Severity Score at Initial			0.108 (0.05)	**0.11, .205**	0.085 (0.049)	-.010, .181	0.053 (0.047)	-.040, .145
Assessment Specific Characteristics								
Days from injury to initial assessment			0.134 (2.44)	-.344, .613	-0.023 (0.24)	-.494, .448	0.305 (0.237)	-.160, .770
Days from injury to first BCTT			1.253 (0.29)	**.683, 1.822**	1.298 (0.284)	**.741, 1.856**	0.791 (0.284)	**.235, 1.348**
Treatment Specific Characteristics								
Total number of SOAP's							3.147 (0.487)	**2.191, 4.103**
Number of SOAP's with visual or vestibular rehab							0.496 (0.685)	-.850, 1.841
Number of BCTT's Performed							1.879 (2.235)	-2.509, 6.266
BCTT Test result					13.173 (2.138)	**8.977, 17.369**	6.588 (2.717)	**1.254, 11.92**
R Square	0.025		0.078		0.118		0.18	
R Square Change	0.025		0.053		0.04		0.006	

CHAPTER 3: EXPANDED DISCUSSION

Despite the significant scientific attention to SRC and persistent concussion symptoms over the last decade, concussion remains a clinical diagnosis based on subjective symptom reporting.[1] Current clinical management for SRC includes the removal of an athlete from play, followed by a stepwise return to sport.[1] Outside these practice guidelines, the use of prevention-based strategies and rehabilitation approaches for persistent symptoms have also been explored and implemented into clinical use. Although significant strides have been made in concussion management, an objective diagnostic marker remains elusive. If found, this would present as a giant leap forward in concussion management. The hope is to pair current evidence-based prevention and treatment strategies with future objective diagnostic techniques to reduce the overall burden SRC.

Concussion prevention

A variety of prevention strategies have been under study for SRC. A 2016 systematic review and meta-analysis of prospective studies evaluated the preventive effect of protective equipment (ie, helmets, face shields, mouthguards), education, or training programs on the incidence of concussion.[43] Of the 15 studies included, only 8 (7 on protective equipment and 1 on education) were included in the meta-analysis. The relative risk of concussion for participants wearing protective equipment relative to standard equipment showed no effect of the intervention (RR=0.82, 95%CI=0.56, 1.20).[43] However, the relative risk of superficial head injury was significantly reduced for participants wearing protective equipment relative to those that did not (RR=0.41 95%CI=0.31, 0.56).[43] Therefore, prospective studies indicate protective equipment can prevent superficial head injury but do not protect against concussion. Perhaps the strongest evidence for prevention of SRC comes from sport rule changes. A prime example of this can be seen in adolescent hockey leagues and the elimination of body checking. In 2011, Ontario provincial policy disallowed body checking in non-elite Pee Wee (ages 11-12) leagues.[44] The effect of this ban on concussion was analyzed by comparing 281 non-elite Pee Wee hockey players from Ontario in the year 2011-2012 to 590 non-elite Pee Wee hockey players in Alberta during 2011-2012 where body checking was permitted. Participants in Alberta were approximately 3 times more likely to receive a concussion when compared to participants in Ontario (IRR=2.83, 95% CI= 1.09, 7.31).[44]

Persistent symptom management

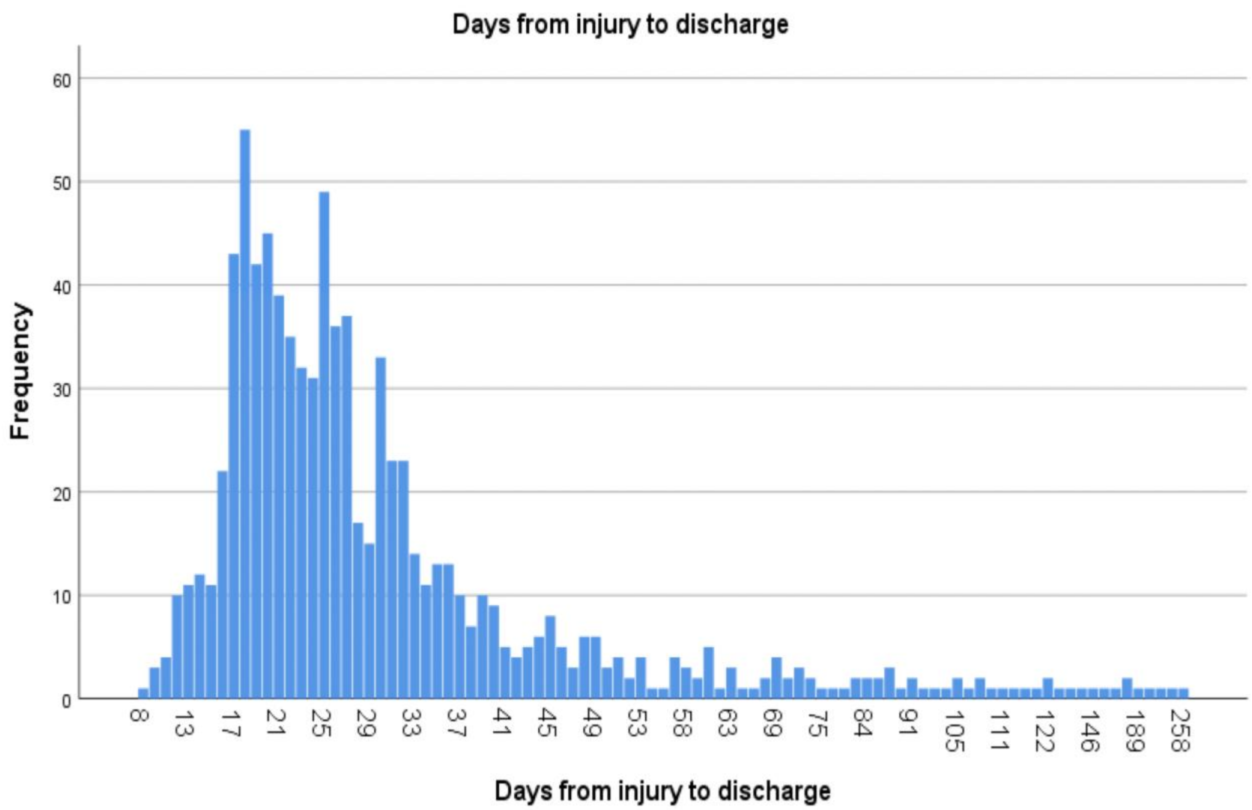
Although strategies to prevent of concussion have become more accepted within youth sporting organizations, management of symptoms for athletes who sustain concussions is also of priority. Most concussions resolve in approximately 10-14 days[1]; however, it is important to seek additional assistance and care if symptoms become persistent. Approaches such as cervical and vestibular rehabilitation, symptom limited aerobic exercise protocol and/or management through psychological approaches have been useful at reducing time to recovery. For example, Schneider et al. randomized 31 individuals diagnosed with SRC to individually designed combinations of cervical spine and vestibular physiotherapy or non-provocative range of motion exercises between November 2010 and October 2011. Patients randomized to treatment were more likely to receive clearance to return to sport at 8 weeks when compared to control (OR=3.91, 95%CI=1.34, 11.34).[45] Leddy et al. randomized 113 participants with SRC to a treatment group of 20 minutes daily sub symptomatic aerobic exercise at 80% of heart rate achieved at symptom exacerbation or daily stretching. Participants randomized to the aerobic exercise group were shown to have a median recovery of 13 days (IQR= 10,18.5) while those randomized to the control group had a median recovery of 17 days (IQR=13,23) (p=0.009).[5] Very few, if any randomized controlled trials exist relating to the use of psychological rehabilitation strategies to reduce recovery time following SRC. This presents as an area for further research. However, this literature does exist in the general mild traumatic brain injury literature and has shown to improve symptoms.[46,47]

Biomarkers of Concussion

If found, an objective biomarker for concussion would allow for timely removal of an athlete from play, differentiation of SRC from other conditions and provide assurance that neurobiological recovery has occurred when athletes return to play. The use of biomarkers currently remains investigational and more information is needed before integrating these novel approaches into future clinical practice. Diffusion Tensor Imaging (DTI) is a non-invasive imaging technique which measures the quantity and direction of water molecule diffusion.[48] Commonly used DTI measures include fractional anisotropy (FA) which relates to the directionality of diffusion and mean diffusivity (MD) which relates to total diffusion within a voxel or region.[49] Changes in FA and MD are used to detect micro-structural changes to white matter following concussion and may correlate with longstanding-concussion symptoms.[50] A 2016 systematic review which aimed to review DTI parameters as a diagnostic tool and predictor of PCS showed common findings of decreased FA in concussed individuals when compared to healthy controls in 7 out 10 ten included studies.[51] However, 3 of the included studies showed no significant changes in FA when compared to healthy controls.[51] The challenge for the use DTI as a biomarker for concussion is that the changes which occur to FA and MD after concussion is not consistent between studies. Furthermore, more research is needed to establish normal values for FA and MD so differences following concussion are compared to a universal standard rather than a healthy control. Parallel to the work in neuroimaging, biochemical markers for concussion are also under study. The most frequently examined biomarker in athletes after SRC is S100B.[52] S100B is a low affinity calcium-binding protein in astrocytes which regulates intracellular levels of calcium. After concussion S100B is released and enters the peripheral blood stream through the Blood Brain Barrier (BBB).[53] A case-control study highlighted this effect through analysis of 36 athletes after SRC and 86 demographically matched controls. Within-patient analysis showed elevated S100B after SRC ($p=0.003$, 67% of patients elevated) while a significant between-group difference was also shown after SRC compared to controls ($p=<0.001$).[54] Unfortunately, S100B like other biomarkers under study is not concussion specific and has shown to be elevated in studies in healthy individuals during exercise.[55]

Until an objective and specific biomarker for SRC exists, it is important to further understanding of currently used outcome measures to advance current clinical practice. Our study showed a significant relationship between a first attempt BCTT and days to recovery. Future studies should assess this relationship in a variety of participant samples and in non-sport related concussion. There is also a need for research into minimally clinically important differences (MCID's)[56] for many outcome measures of concussion, including the BCTT.

FIGURE 2: OVERAL DISTRIBUTION OF OUTCOME VARIABLE – TIME TO RECOVERY



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