Heart Rate Variability and Concussion: Exploring Neurophysiological Variation in Youth Athletes

by

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Rehabilitation Sciences Institute
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Abstract

Sport participation makes a significant contribution to youth development, but place youth at an increased risk for sustaining a concussion. Neurocognitive testing and the monitoring of self-reported concussion symptoms have been the anchor in making return-to-activity decisions. While these methods have been purported to add clinical value, their trajectory may not overlap with the physiological mechanisms at play following concussion. Multi-modal assessments corroborate objective physiological measures with traditional subjective symptom reporting. Heart rate variability is a non-invasive physiological indicator of the autonomic nervous system, capturing the reciprocal interplay between the sympathetic and parasympathetic nervous systems. The first study examines the relationship between heart rate variability and subjective symptom reporting in a healthy population of youth; a significant relationship between daily reported cognitive symptoms and a decrease in HRV was found, while considering age and sex. The second study is a longitudinal, matched control study that explores the physiological trajectory of heart rate variability across days post concussion; the relationship between concussion symptoms and HRV was found to vary across days post injury, when considering symptom status and a comparison to controls. The third and final study is a pilot and feasibility study that aims to bridge physiological and functional outcomes by exploring the role of
mindfulness-based yoga in youth with persistent concussion symptoms; here, preliminary trends of increased self-efficacy and physical activity mirrored increases in HRV. The thesis concludes with a novel conceptual model, highlighting the various person, occupation and environment factors which influence concussion recovery, irrespective of the pathophysiological characteristics of the injury. Taken together, this doctoral work identified significant trends in a novel, physiological measure which traversed, healthy, concussed and persistent concussion samples. This thesis provides a foundation for the study of physiological stress responses in concussion - a non-specific, complex injury, which is experienced at high rates by an understudied population.
In the midst of a chaotic signal, there is always a trend or pattern -- a lesson to be discovered.

In the pursuit of attempting to understand a complex and variable physiological signal, my doctoral work taught me to “make sense of the noise” and to appreciate the nuances of human participants, who go about their daily lives in meaningful ways. Without this context, the understanding of basic science principles cannot fully be understood.

On a personal note, my chaotic doctoral journey also taught me about personal and professional growth – the ability to accept failure and think critically about future improvement, the skills of efficient oral and written communication, and most of all - to build a team of like-minded individuals who share the same passion that I do. I would not have been able to achieve even a fraction of my accomplishments if it wasn’t for the following people. I would like to take this opportunity to highlight and thank them immensely.

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Chapter 1
Utilizing a Biopsychosocial Approach to Exploring Heart Rate Variability and Youth Concussion

1 Introduction

1.1 Epidemiology

Sport and physical activity play a key role in the lives of Canadian youth. Engagement in sport activity creates a sense of belonging and makes a significant contribution to the physical and mental health of youth (Eklund & Tenenbaum, 2014). The Government of Canada released an online statement that recognized concussion in sport as a serious public health issue due to the potential short- and long-term consequences (Government of Canada, 2017). Among 10-18 year olds who present to the emergency department, 64% of those visits are related to participation in physical activity and recreation (Government of Canada, 2017). Among those children and youth who visit the emergency department for a sports-related head injury, 39% were diagnosed with concussion. Between 2004 and 2014, football, soccer and hockey showed a >40% increase in rates of reported head injury relative to other sport injuries in children and youth (Government of Canada, 2017). Macpherson, Fridman, Scolnik, Corallo, & Guttmann (2014) revealed that between 2003-2010 within the province of Ontario, the rate of reported concussions per 100,000 increased from 466.7 to 754.3 for boys and from 208.6 to 440.7 for girls; these increased rates were mirrored by an increase in the use of health services for concussion. More recently, Zemek et al. (2017) revealed that there were approximately 176,000 pediatric visits for concussion in the emergency department in Ontario, with a 4.4 fold increase per 100,000 from 2003-2013.

The association between age and concussion was recently investigated in a rigorous systematic review. This review revealed that a lack of clarity and consistency exist within studies investigating the differences between adult versus child and youth management of concussion regarding the effects of age, symptomatology and length of recovery (Davis et al., 2017). However, the review outlined clinical recommendations, which stated that youth should be managed uniquely from adults. It has been documented that children and youth typically return to activity within 4 weeks following their concussion (Zemek et al., 2016). However, a significant proportion continues to experience concussion symptoms beyond that length of time. The aforementioned Davis et al. (2017) review cited the largest Canadian cohort study to date,
which demonstrated that 31% of children and youth are still symptomatic at 4 weeks post-injury; specifically, those who were 13 years or older were found to have a significantly higher risk of developing persistent symptoms that lasted beyond 4 weeks (Zemek et al., 2016). Similarly, other studies have shown that adolescents in particular, are more susceptible to sports-related injuries, accounting for 30% of pediatric concussions (Meehan & Mannix, 2010). Specifically within the school setting, adolescents appear to report a greater number of, and more severe concussion symptoms compared to younger children, which may be related to their concern regarding the academic effects of concussion (Carson et al., 2014; Lovell et al., 2003; Ransom et al., 2015). In sum, it is recommended that adolescent-specific paradigms be applied to those 13-18 years old (Davis et al., 2017).

The association between length of recovery and sex has also been investigated within the context of adolescent populations following concussion. In an epidemiological study, Fridman, Fraser-Thomas, McFaul, & Macpherson (2013) found that girls sustained a higher percentage of concussions in 6 out of 13 sports analyzed. Similarly, Zemek et al. (2016) found that the female sex was a significant predictor of prolonged concussion recovery, in addition to other predictors such as presence of headaches, sensitivity to noise and answering questions more slowly. Finally, in the systematic review by Davis et al. (2017), all 18 studies identified the female sex as a significant predictor of persistent symptoms. Taken together, females have been shown to experience a greater number and more severe symptoms compared to males. Despite females being at greater risk, sex specific management strategies have not been established and further investigation is needed in order to tailor return-to-activity guidelines based on individual needs.

1.2 Definition of Concussion

There has been debate about whether concussion falls on the traumatic brain injury (TBI) spectrum given the lesser degree of diffuse structural change seen compared to moderate or severe TBI, or whether it results in reversible physiological changes (McCrory et al., 2017). Nonetheless, international expert consensus conveyed within the recent 5th International Concussion in Sport Consensus Statement (McCrory et al., 2017), defined concussion as a traumatic brain injury induced by biomechanical forces. A concussion can be caused by a direct blow to the head or on the body generating force to the head, and results in neurological impairment, which resolves spontaneously. Concussion has been deemed a functional, rather
than structural injury, as no abnormality is seen on standard structural imaging studies. Concussion does not necessarily involve the loss of consciousness. Finally, the resolution of clinical symptoms follows a sequential course (McCrorry et al., 2017).

Concussion results in the confluence of physical, cognitive, emotional and fatigue symptoms (Gioia & Collins, 2006). Physical symptoms include headaches, dizziness, blurred vision, and sensitivity to noise and light. Cognitive symptoms capture challenges with concentration and remembering, slow thinking and general mental fog. Fatigue symptoms include sleeping too much or too little and feeling drowsy (Sady, Vaughan, & Gioia, 2014). Finally, emotional symptoms capture an individual’s rating of sadness, irritability and nervousness (Sady et al., 2014). From a broader functional perspective, these symptoms can manifest as a barrier to engagement in daily meaningful activity such as participation in school and sport, and spending time with family and friends (Paniccia & Reed, 2017; Reed, 2011).

1.3 Utilizing The Biopsychosocial Model

1.3.1 Physiological mechanisms of concussion

A major factor in the symptomatology of mTBI has been the suspected dysfunction of the autonomic nervous system (ANS). The central autonomic network is a network located within the central nervous system; it involves the cerebral cortex (insular and medial prefrontal regions), amygdala, hypothalamus, and brainstem centers (McCorry, 2007). The major efferent source of autonomic modulation and cardiovascular responses involves the relationships among the prefrontal cortex and amygdala, and the heart (Bishop et al., 2017; Conder & Conder, 2014; Thayer & Lane, 2009). The ANS is comprised of two branches; the parasympathetic and sympathetic nervous system. These two branches, while they operate reciprocally, respond to environmental demands with their own idiosyncrasies. The parasympathetic nervous system has less of an influence on peripheral vasculature but is active during periods of energy restoration, allowing the viscera to relax (i.e., decrease heart rate, promote gastrointestinal motility). Conversely, the sympathetic nervous system is activated when stressors are presented and induces a “flight or fight” reaction (Esterov & Greenwald, 2017). Within this whole body reaction, the release of epinephrine and norepinephrine cause widespread vasoconstriction. Here,
heart rate increases, gastrointestinal function is halted and the upper and lower extremities prepare for action (Esterov & Greenwald, 2017).

To assess the activity of the ANS following concussion, the noninvasive technique of collecting heart rate to quantify heart rate variability (HRV) has been employed across an array of clinical conditions, which include but are not limited to myocardial infarction (Buccelletti et al., 2009), diabetes (Kudat et al., 2006; Schroeder et al., 2005), mental health issues (Koenig, Kemp, Beauchaine, Thayer, & Kaess, 2016; Paniccia, Paniccia, Thomas, Taha, & Reed, 2017), and most recently traumatic brain injury (Esterov & Greenwald, 2017; Hutchison et al., 2017; Willer & Leddy, 2006). The sympathetic and parasympathetic nervous systems act on the sinoatrial node (natural electrical pacemaker) of the heart to generate time variations between RR intervals in response to internal and external stressors/stimuli. The beat-to-beat interval value across a time series is then used to compute time and frequency domain measures. Time domain variables capture overall variability of the heart, whereas frequency domain variables capture the periodic oscillations of heart rate and provide information on the specific branches of the ANS (Aubert, Seps, & Beckers, 2003; Esterov & Greenwald, 2017; “Heart rate variability,” 1996). For a detailed explanation of HRV measures, see Chapters 2 and 3, methods. While there are no specific guidelines/values on what constitutes as healthy versus unhealthy HRV, typically, sympathovagal balance will be reflected in higher HRV, in which the individual is in a state of vagal dominance (Kleiger, Stein, & Bigger, 2005; Shaffer, McCratty, & Zerr, 2014; Sztajzel, 2004). Here, the individual is able to respond flexibly and adapts to meet environmental demands. Conversely, lower HRV suggests that the ANS cannot modulate heart rate as efficiently (Abaji, Curnier, Moore, & Ellemberg, 2016), with challenges to adaptation and responding to environmental stressors (Shaffer et al., 2014). Within the emerging literature on HRV, a recent systematic review revealed that the effect of concussion on HRV did show some evidence of altered cardiac autonomic functioning as a result of changes in autonomic inputs caused by physical activity, but conflicting evidence was shown during resting states (Blake, McKay, Meeuwisse, & Emery, 2016). Spanning the literature to date, however, there are limitations in applying these findings to a youth athlete population, across multiple time points and with a sufficient sample size (Blake et al., 2016). A major goal of this thesis is to directly address these gaps by examining youth athletes across a spectrum of healthy, concussed and persistent symptom states.
1.3.2 Uniqueness of youth athletes and psychosocial stressors

From a developmental standpoint, youth are in a period of rapid and substantial neurodevelopment (Davis et al., 2017; Keightley et al., 2014; Reed et al., 2014). The interactions youth have with their daily environments provide a rich source of learning in physical, cognitive and emotional domains. The opportunity to engage independently in these domains of learning is halted when a youth sustains a concussion (Reed, 2011). Here, youth are instructed to physically and cognitively rest for 24-48 hours, and engage in symptom-limited activity thereafter. As concussion symptoms resolve, concussed individuals are educated on following the gradual return-to-activity guidelines of re-integrating back to daily life (Davis et al., 2017). Compared to the average timeline of a 7-10 day recovery period for adults (McCrory et al., 2013), youth experience an average recovery period of 4 weeks following concussion (Davis et al., 2017; Zemek et al., 2016).

Regarding the context of sport participation, it is no surprise that physical activity promotes the emergence and utilization of executive functions needed to regulate actions and achieve goals (Eime, Young, Harvey, Charity, & Payne, 2013). Moreover, the ability to cope with a diverse occupational repertoire (e.g., academic achievement and sport competition) is integral to their success in each of those activities. Thus, compared to adults, youth athletes are in an active process of learning how to manage multiple competing demands on a regular basis (school, sport participation, extracurricular activities), while continuing development toward adulthood. When there is a barrier to engaging in a sporting routine, the demands of training volume and intense exercise in competitive athletics may serve as a source of psychosocial stress. While daily psychosocial stressors are part of youth development, concussion can be viewed as a significant cause of stress (Paniccia & Reed, 2017).

It also important to consider the culture of competitive sport and the impact it has on how youth athletes respond to a concussion. For example, in a sample of 18 to 21 year old male athletes, the appraisal of the consequences of concussion had strong predictive value on reporting concussion and the symptoms they were experiencing. Factors related to reporting were related to short-term athletic performance: being prohibited from games, decreasing team performance, and not being able to participate in practice (Kroshus, Baugh, Daneshvar, & Viswanath, 2014). Linking these findings to the traditional use of subjective symptom reporting, it becomes challenging to gauge
how an athlete is truly feeling following concussion, given their high incentive to return to meaningful activity. This thesis does not directly measure the impact of these psychosocial stressors, however, the context of youth athletes does need to be explored in order to enhance the interpretation of neurophysiological findings and consider future areas of research. Nevertheless, the overarching aim of this thesis is to corroborate subjective self-reports with objective physiological indicators such as HRV to enable an enhanced understanding of the recovery trajectory in youth athletes.

1.3.3 Applying a holistic model to concussion assessment and treatment

The biopsychosocial (BPS) model (Figure 1.1) connects the various biological and psychosocial factors that are implicated in injury recovery and rehabilitation outcomes (Hatala, 2012). Widely embraced in the medical and healthy psychology fields, the BPS model is used as a guiding framework for contemporary research and practice (Adler, 2009; Schwartz, 1982). Here biological factors can include pre-injury physiology, the age and sex of the individual, and the physiological response that ensues following an injury. Broadly, the psychosocial factors can be characterized by how the individual perceives their injury and the symptoms they report as well as how they decide to respond to an injury in terms of compliance to treatment recommendations (Manley et al., 2017). These biological and psychosocial factors do not stand alone in the way they impact health outcomes, but rather interact in the context of everyday life stressors to influence recovery from an injury. Perna, Antoni, Baum, Gordon, & Schneiderman (2003) have argued that in order to fully capture the potential pathways mediating the relationship between injury and outcome, the dynamic interaction between these all-encompassing factors need to be considered. The BPS model is used within this thesis as a conceptual framework, connecting physiological mechanisms of concussion with characteristics of the youth athlete population. Across healthy, concussed and persistent symptoms samples, this thesis highlights the variation in a neurophysiological signal. The purpose of using the BPS model to conceptualize this thesis is two-fold. Firstly, the BPS model can assist with elucidating the physiological response following concussion both across a recovery trajectory and in those youth who experience a prolonged recovery. Secondly, the BPS model allows for flexibility in the interpretation of the physiological response following concussion as it considers the myriad of biological (age, sex, baseline physiology) and psychosocial (symptom reporting) factors that impact health outcomes (self-efficacy, participation in physical activity, length of recovery). Ultimately, the aim of this
thesis is to elucidate the physiological response of concussive injury in the context of overlooked factors, which may play a significant role in understanding the physiological trajectory post-concussion in youth athletes. Due to the paucity of research in examining the physiological mechanism of concussion, especially within youth athletes, this model provides a foundation to build a comprehensive program of research with the aim to ultimately improve concussion management and outcomes.

Figure 1.1: The Biopsychosocial Model. Adapted from (Eklund & Tenenbaum, 2014) to illustrate its application to examining physiological measures following concussion in youth.
1.3.4 Health outcomes

The evaluation of health outcomes following concussion is multifaceted and complex, with a variety of physiological, behavioural and psychosocial factors that influence recovery trajectories (Davis et al., 2017; Manley et al., 2017). One of the foundational first steps to conceptualize recovery is to understand the target population at baseline, while they are healthy and uninjured. Healthy youth athletes, compared to non-athletes have different ANS functioning whereby healthy youth athletes have been shown to have higher HRV; the sport environment and the concomitant physical training results in efficient cardiovascular function (Aubert et al., 2003). Athletes often train at high volumes and intensities, resulting in physiological adaptations, which are present even when the athlete is not directly engaged in exercise (Aubert et al., 2003; da Silva, de Oliveira, Silveira, Mello, & Deslandes, 2015). Thus, their baseline ANS function should be considered when interpreting change in HRV following a concussive injury.

It is important to note that the concept/definition of concussion recovery has been inconsistent in the literature to date (Manley et al., 2017). While ambiguous, there has been recent interest in investigating clinical versus physiological recovery (Ellis, Leddy, & Willer, 2016; McCrory et al., 2017; Willer & Leddy, 2006). With respect to concussion, clinical recovery is often defined as a resolution of post-concussion symptoms (McCrory et al., 2017), however, the boundaries of physiological recovery are still unknown and longitudinal studies have become key to this investigation (Blake et al., 2016). This thesis attempts to map the recovery trajectory of youth following concussion (Chapter 2), by corroborating change in clinical, self-reported symptoms with changes in HRV across days post injury.

Psychosocial factors, such as an individual’s personality, history of stress or previous injury, and coping resources may also mediate physiological responses following concussion (Azulay, Smart, Mott, & Cicerone, 2013; Manley et al., 2017). As mentioned previously, negative life stressors such as the emotional distress of not being able to engage in pre-injury activity levels can act as a significant source of lowered self-efficacy and a lack of engagement in once enjoyed occupations (Hanna-Pladdy, Berry, Bennett, Phillips, & Gouvier, 2001; Jonsson & Andersson, 2013). These emotions can then feedback to influence ANS activity, yielding the release of catecholamines such as epinephrine and norepinephrine. Target organs such as the heart contain receptors for these catecholamines, and the ANS affects the heart by increasing heart rate and
decreasing HRV (McCorry, 2007). A functional example is youth athletes who experience persistent concussion symptoms. Here, the prolonged lack of engagement in sport and school tasks often lead to feelings of social isolation and decreased confidence in being able to perform at pre-injury levels (Jonsson & Andersson, 2013; Paniccia & Reed, 2017; Reed, 2011). These may indeed manifest as physiological responses, however, understanding the mechanism of these responses is challenging. Research has demonstrated that the experience of persistent concussion symptoms often occurs beyond the neuropathology of concussion, as a secondary reaction to the injury (Ellis et al., 2016).

Finally, the majority of research in youth concussion has focused on the identification and subsequent management of concussion (return-to-play and return-to-learn; Davis et al., 2017; McCrory et al., 2017). Little research has been conducted in the realm of exploratory clinical interventions and the role they play in the recovery trajectory in youth following concussion. It is likely that physical activity tolerance, psychological well being and social supports should be targeted within clinical interventions. It is difficult to incorporate all of these domains, however, active rehabilitation approaches have begun to account for the multifaceted nature of promoting recovery, with promising findings suggesting that symptom-limited activity enables recovery (Gagnon, 2013; Gagnon, Grilli, Friedman, & Iverson, 2016; Grool et al., 2016; Reed et al., 2015). The final goal of this thesis was to examine a novel clinical intervention (mindfulness-based yoga) for youth with persistent concussion symptoms, while considering both physiological (HRV) and functional outcomes (symptoms, self-efficacy and participation; Chapter 4). While traversing healthy, concussed and persistent symptom youth athlete samples, this thesis aims to build a holistic picture of health outcome/recovery.

1.4 Purpose and Objectives

Participation in sport provides a rich source of physical, psychological and social development opportunities for youth. However, youth who participate in sport are six times more likely to sustain a concussion (Browne, 2006). While concussion literature has predominantly focused on adult and collegiate athletes, attention has shifted to examine youth. The differences between youth and adults have been challenging to decipher given the lack of consistency in capturing age, recovery definitions and the limitations in methodology (Davis et al., 2017; Manley et al., 2017). Nonetheless, the youth brain warrants tailored attention, given the critical developmental
milestones that are established during this stage. According to the most recent Concussion in Sport Consensus Statement, concussion research is limited by the lack of pediatric focus, small sample size, and lack of sufficient follow-up time points (McCrory et al., 2017). This doctoral dissertation aims to fill these research gaps with the ultimate goal of enhancing knowledge in the field of pediatric concussion. This thesis is framed within the BPS model to enable a broad and integrated perspective on this topic.

The objectives of this research, in line with investigating the physiological mechanisms of concussion, the unique youth athlete population and the psychosocial factors that contribute to concussion recovery, are:

1. To describe natural variations in HRV in a healthy sample of youth athletes, when considering age, sex and concussion-like factors (symptom-reporting and concussion history).

2. To explore the effect of concussion on HRV in youth athletes across the recovery trajectory.

3. To examine the relationship between traditional, subjective self-report (concussion symptom reporting domains) and objective HRV measures across days post injury in youth athletes.

4. To explore the feasibility of a clinical intervention pilot study, examining the impact of mindfulness-based yoga on physiological (HRV) and functional outcomes (self-efficacy and participation) in youth with persistent concussion symptoms.

5. To propose a model of concussion management grounded in the values of occupational therapy and rehabilitation sciences, which reflect a more holistic account of the factors that contribute to recovery following youth concussion.

1.5 Thesis Organization

The layout of this thesis is manuscript-style, with a total of six chapters. Chapters 1, 5 and 6 are the introduction, novel model proposition and summary/conclusions, respectively. Chapters 2, 3 and 4 are composed of the three independent studies/manuscripts, which are described below.
Preceding each chapter is an abstract summary, as well as a statement highlighting the chapter’s stage of publication.

Chapter 2, entitled “Heart rate variability in non-concussed youth athletes: Exploring the effect of age, sex and concussion-like symptoms” investigates the influence of demographic and concussion-related factors on ANS function. This satisfies objective 1 of this thesis: to describe natural variations in HRV in a healthy sample of youth athletes, when considering age, sex and concussion-like factors (symptom-reporting and concussion history). This chapter provides the foundation on which the subsequent chapters are built, in considering key factors that drive variation in a physiological signal within a non-injured, healthy sample of youth athletes. To date, the investigation of concussion and HRV has highlighted the major limitation of not accounting for baseline trends to assist in the interpretation of post-concussion values (Blake et al., 2016; Hutchison et al., 2017). This study aims to fill that gap by describing the natural variation in HRV between healthy youth athletes. Further, this study is unique in that it examines the relationship between a traditional subjective clinical measure (concussion-like symptoms) and HRV. Here, concussion-like symptom domains (physical, cognitive, fatigue and emotional) are individually investigated to capture how daily reports of non-specific symptoms impact ANS function. Recent studies have shown that concussion-like symptoms are indeed endorsed by healthy individuals (Hunt, Paniccia, Reed, & Keightley, 2016; Iverson et al., 2015; Iverson & Lange, 2003; Sady et al., 2014), where expecting no symptoms on daily, regular basis is unrealistic, especially in using baseline comparisons to benchmark change following concussion (Hunt et al., 2016). Within the BPS framework, this chapter addresses the physiological mechanisms of HRV within the context of everyday reports of physical, cognitive, fatigue and emotional symptoms, providing a basis to understanding the stressors that youth typically experience on a daily basis.

Chapter 3, entitled “Heart rate variability following youth concussion: How do autonomic regulation and concussion symptoms differ over time post injury?” explores a longitudinal, matched control study that examines the effect of concussion on HRV, specifically across days post injury. This chapter addresses objective 2 of the thesis: to explore the effect of concussion on HRV in youth athletes across the recovery trajectory; and, objective 3 of the thesis: to examine the relationship between traditional, subjective self-report (concussion symptom reporting domains) and objective HRV measures across days post injury in youth athletes.
Unlike the structured clinical time points (symptomatic, asymptomatic, return-to-play) presented in the literature (Abaji et al., 2016; Hutchison et al., 2017; Senthinathan, Mainwaring, & Hutchison, 2017), this study aimed to capture a more dynamic and fluid account of how HRV changes following concussion over repeated follow-up time points. Further, the uniqueness of this study is that: (1) this is the first youth athlete concussion HRV study; and, (2) changes in HRV were evaluated over the course of clinical follow-up time points where standardized education was provided to each concussed participant within this study. Thus, this chapter reflects the physiological (HRV), health outcome (days post injury, symptom reporting along trajectory), and indirect behavioural aspects (receiving clinical education) of the BPS model. Here, concussed youth athletes not only had to report their subjective concussion symptoms, but also did so in the context of receiving education on how to gradually engage in cognitive and physical activity based on their symptoms. From a research standpoint, this study highlights the relationship between subjective symptom reporting and objective physiological indicators across the recovery trajectory. The clinical implication of this investigation is the understanding that physiological changes following concussive injury need to be considered within the context of other factors (symptoms, clinical education offered) which can influence (positively or negatively) feedback to ANS function. Finally, understanding the relationship between clinical and physiological measures can highlight potential periods where the risk of re-injury may be heightened and it is unsafe to return to play.

Chapter 4, entitled “Mindfulness-based yoga for youth with persistent concussion: A pilot and feasibility study” examines, the role of clinical intervention in youth experiencing a prolonged recovery from concussion. This study addresses objective 4 of this thesis: to explore the feasibility of a clinical intervention pilot study, examining the impact of mindfulness-based yoga intervention on physiological (HRV) and functional outcomes (self-efficacy and participation) in youth with persistent concussion symptoms. The novelty of this study is the bridge between examining physiological change alongside functional reports of physical activity, self-efficacy and participation. While a pilot study, this makes a significant clinical contribution to the field of pediatric concussion as it incorporates a multitude of components, shown to be affected by concussion, especially within the persistent symptom population (i.e., reduced self-efficacy, persistent ANS dysfunction, significant decline in physical activity, lack of engagement in daily activities; Azulay et al., 2013; Ellis et al., 2016; Jonsson & Andersson, 2013; Paniccia & Reed,
2017; Willer & Leddy, 2006). Chapters 2 and 3 built the foundation to this final study and informed the need to not only evaluate HRV within a clinical setting but also begin to examine psychosocial/functional measures that can inform how the youth is performing on a daily basis. This study directly aligns with the BPS model, specifically the physiological mechanism (HRV), behaviour mechanisms (increased symptom reporting and lack of participation) and health outcomes (change in ANS function and functional measures across short- and long-term follow-up time points).

Chapter 5, entitled “Dove and hawk profiles in youth concussion: Re-thinking occupational performance” provides a novel model of understanding persistent concussion across a spectrum of profiles driven by evolutionary theory on stress response and maintaining homeostasis. This chapter addresses objective 5 of the thesis: to propose a model of concussion management grounded in the values of occupational therapy and rehabilitations sciences, which reflect a more holistic account of the factors that contribute to recovery following youth concussion. The approach to concussion management aligns with the BPS model in taking a holistic approach in understanding how a youth performs in meaningful areas of their life (e.g., school, sport, social networks) following a concussion. Further, this chapter goes beyond the physiological mechanisms of concussion to draw attention to the diverse spectrum of profiles that youth with concussion symptoms display and how those profiles impact how youth approach their recovery (i.e., take a passive approach and become anxious and retreat from meaningful activity or take an active approach and return to activity prematurely). The model postulates that most of the research to date has conceptualized youth with persistent symptoms as complex and heterogeneous. This chapter aims to disentangle this complexity by considering the various person, occupation and environmental factors that transact to influence functional performance in daily activities (Law et al., 1996).

Chapter 6 is the concluding chapter of this dissertation and summarizes the main research findings, states the research and clinical implications of this work and provides suggestions for future research direction.
1.6 References


Conder, R. L., & Conder, A. A. (2014). Heart rate variability interventions for concussion and


Macpherson, A., Fridman, L., Scolnik, M., Corallo, A., & Guttmann, A. (2014). A population-based study of paediatric emergency department and office visits for concussions from


Chapter 2
Heart Rate Variability in Non-Concussed Youth Athletes: Exploring the Effect of Age, Sex and Concussion-like Symptoms

2 Overview

This chapter presents baseline values and trends of HRV variables in youth athletes, when considering demographic (age and sex) and concussion-like (symptom domains and concussion history) factors. By examining a sample of healthy, non-injured youth athletes, this chapter aims to create a foundation on which post-concussion HRV values can be interpreted. This chapter explores the physiological mechanisms at play in a healthy youth athletes and the daily stressors experienced in the form of concussion-like symptoms.

An abbreviated form of this chapter has been submitted to Frontiers in Neurology – Autonomic Neuroscience; currently, the manuscript has been endorsed for publication. This journal provides a forum for the dissemination of research that integrates all levels of autonomic function, including the development and dysfunction across a variety of healthy and clinical populations.


2.1 Abstract

Background: Heart rate variability (HRV) is a novel, non-invasive neurophysiological measure of the autonomic nervous system regulation emerging in the concussion literature as a mechanism of physiological injury. To date, most concussion studies have focused on the university-aged athlete with no research examining active youths. A first step to understanding the role that HRV plays in a concussed sample is to explore the factors that drive change in a healthy population. Further, corroborating potential change in HRV alongside traditional subjective self-report measures (concussion symptoms) provides a foundation for interpreting change following concussion. The objectives of the current study were to: (1) explore the influence of age and sex on HRV in healthy youth athletes; and, (2) examine the relationship
between HRV and baseline/pre-injury concussion symptom domains (physical, cognitive, emotional, fatigue). **Method:** Healthy, non-concussed youth athletes 13-18 years of age (N=294, female=166 [56.5%], male=128 [43.5%]) participated in this cross-sectional study. Age and sex, as well as concussion-like symptoms, were collected as part of a baseline/pre-injury assessment. Concussion-like symptoms were collected via the Post Concussion Symptom Inventory (PCSI) and domain scores were computed for physical, cognitive, emotional and fatigue domains. HRV was collected using the Polar RS800CX chest strap and heart rate watch for a duration of 24 hours. **Outcome Measures:** HRV, collected over 24 hours was the primary outcome of interest and included time (SDNN, RMSSD, pNN50) and frequency (e.g., HF, Total Power) domain measures. For statistical analysis, variables were logarithmically transformed to increase robustness of linear regression models. **Results:** Significant age effects revealed that older participants displayed higher HRV compared to younger participants. Females displayed significantly lower HRV compared to males. A significant interaction effect between concussion-like symptoms and HRV indicated differential patterns as a function of sex. Finally, youth athletes who reported more cognitive symptoms had lower HRV. There were no main effects of physical, emotional, and fatigue symptom domains on HRV. **Conclusions:** This study highlights the variability in HRV present in a healthy, non-concussed youth athlete sample. Baseline/pre-injury trends in HRV underscore the value in understanding key demographic and concussion-like factors that drive change in HRV. These may or may not contribute to differential recovery trajectories following concussion and longitudinal research with an injured population is warranted.

## 2.2 Introduction

The study of concussion in youth athletes has received increasingly more attention over the past decade, even more so since the recent Berlin Concussion Consensus Statement highlighted their focus on pediatrics (Davis et al., 2017). Internationally, it is estimated that 4 million children and youth present to the emergency department with a concussion annually (Crowe, Babl, Anderson, & Catroppa, 2009; Lyttle, Crowe, Oakley, Dunning, & Babl, 2012). As defined by the most recent consensus statement, a concussion is a form of traumatic brain injury induced by biomechanical forces; this can be caused by a direct blow to the head, or elsewhere on the body generating force to the head (McCroy et al., 2017). Integral to this definition is the statement that concussion presents as a functional disturbance rather than a structural injury. This
highlights the complexity in understanding the neurological underpinnings of this injury and the variety of mechanisms at play. The state of knowledge on establishing time of recovery has determined that a gold standard to assess recovery is lacking, with a current focus on the reduction in subjective symptom reporting (McCrory et al., 2017). Emerging research has highlighted the potential of exploring change in physiological measures following concussion, in the context of a multi-modal approach (Ellis, Leddy, & Willer, 2016; Reed et al., 2014). However, a foundational first step in examining physiological measures in youth athletes following concussion is to understand natural variations present in a healthy population, alongside traditionally used clinical measures.

2.2.1 Heart rate variability

The cardiovascular system is predominantly controlled by autonomic regulation through the activity of sympathetic and parasympathetic branches of the autonomic nervous system (ANS). The cardiovascular control area exists within the brainstem, through sympathetic and parasympathetic nerves (Aubert, Seps, & Beckers, 2003), which work together to create sympathovagal balance or homeostasis. The balanced interplay between these two branches ultimately results in variations of beat-to-beat time intervals, in response to a variety of physical, environmental and mental factors. Since the 1970s, measures of cardiovascular autonomic function have been used to evaluate clinical status in adults at risk for myocardial morbidity and mortality (Ewing, Campbell, & Clarke, 1978; Ewing, Campbell, Murray, Neilson, & Clarke, 1978; Ewing, Martyn, Young, & Clarke, 1985), and has been utilized extensively in the field of psychophysiology to characterize mental health issues across clinical and non-clinical populations (Baumert et al., 2006; Friedman, 2007; Paniccia, Paniccia, Thomas, Taha, & Reed, 2017). Heart rate variability (HRV), is the non-invasive quantification of these beat-to-beat variations and has been recognized as a method to link neuroscience with cardiology in order to examine autonomic fluctuations (Aubert et al., 2003). Reduced HRV represents an attenuation of the autonomic regulatory capacity to support flexible adjustments in response to the environment, whereas increased HRV is reflective of good overall health and an ability to adequately respond to stressors (Thayer & Sternberg, 2006).

Previous research, as outlined in a systematic review, has illustrated preliminary findings on the acute and chronic effects of concussion on HRV (Blake, McKay, Meeuwisse, & Emery, 2016).
However, healthy ANS functioning within youth athletes has not yet been characterized and knowing this information could significantly enhance our understanding of post-injury comparisons and the variety of factors, demographic and concussion-related, that drive change in HRV. There have been numerous adult population-based studies on healthy HRV values stratified by age, sex, medication, and physical activity (Berntson, Cacioppo, & Quigley, 1993; Malpas & Purdie, 1990; Stein, Kleiger, & Rottman, 1997; Tsuji et al., 1996). However, unique developmental changes and pediatric milestones preclude these findings from being extrapolated to youth, and more specifically youth athletes. Youth are uniquely different from adults due to the rapid and substantial neurodevelopment underway. Specific to ANS function, youth are in a transient state of development where pubertal status plays a role in the balance between parasympathetic and sympathetic activity (Chen, Chiu, Lee, Sheen, & Jeng, 2012).

2.2.2 ANS function and development

Studies observing HRV across the lifespan have shown a progressive maturation of the ANS during childhood with trends of increased HRV up to age 6 years, followed by a decline toward adolescence (Finley & Nugent, 1995; Finley, Nugent, & Hellenbrand, 1987; Goto et al., 1997; Massin, 2000; Massin & von Bernuth, 1997), with HRV values reaching a maximum at the age of 30 years old (Pikkujämsä et al., 1999), and a decline into older adulthood (Beckers, 2006; Iyengar, Peng, Morin, Goldberger, & Lipsitz, 1996; Pikkujämsä et al., 1999; Umetani, Singer, McCraty, & Atkinson, 1998). In a cross-sectional study that investigated developmental trends of HRV from pre-school to adolescence, it was found that parasympathetic signals (i.e., HF) did not show change up to puberty, however decreased during adolescence (14-22 years old; Cysarz et al., 2011). It has been hypothesized that the variation during childhood and adolescence is related to the maturation of the different regulatory mechanisms and determinants of the ANS, whereas the variation in older adulthood reflects their deterioration. Trends have been observed across a variety of age groups; however, due to the dearth of literature that specifically examines the youth/adolescent population, one aim of this study is to investigate the role of development on HRV in youth athletes.

2.2.3 Sex differences

Sex differences in ANS function have been documented extensively in the adult population. In a recent meta-analysis examining sex differences in HRV, results revealed that females have a
greater mean heart rate reflected by a smaller mean RR interval. Here, females show lower HRV, specifically within long-term recordings (Koenig & Thayer, 2016). Further, females showed high HF power, which authors stated may be indicative of greater parasympathetic dominance in females and sympathetic dominance in males. However, of the 172 studies included in the meta-analysis, only 7 studies focused on the adolescent population (10-20 years old), highlighting the scarcity of literature in this area. Moreover, these sex differences may manifest differently during the period of adolescence. In a cross-sectional study with a participant group made up of adolescents between the ages of 14 to 22 years old, males consistently demonstrated higher values across SDNN, HF and LF, compared to females, which may reflect gender specific aspects of maturation (Cysarz et al., 2011). Similarly, Faulkner et al. (2003) also found that adolescent girls (13-18 years old), exhibit lower overall HRV (SDNN, SDANN) and cardiac parasympathetic activity (RMSSD, pNN50, HF power). Understanding the role that sex plays in ANS function has the potential to enhance our understanding of the differential recovery trajectory seen following concussion whereby females report more symptoms and are more at risk for prolonged recovery compared to males (Zemek et al., 2016). It is unclear if these differences are related to changes in cardiac autonomic modulation and this study aims to contribute to that exploration.

2.2.4 The unique athlete

While several studies have explored the normal variation in ANS function across infants, children and adolescents (Finley & Nugent, 1995; Finley et al., 1987; Goto et al., 1997; Massin, 2000; Massin & von Bernuth, 1997), little is known about how these trends are reflected within an athlete-specific population. Athletes, compared to non-athletes, have been described as having increased ANS plasticity, influenced by the changing environmental conditions present in sport participation, which ultimately result in an improved ability to be flexible and adaptable (Gavrilova, 2016). Goldsmith et al. (1997) also stated that participation in sport can significantly impact vagal modulation-parasympathetic activity. For youth athletes who have been involved in sport from a young age, long-term physical training likely influences cardiac rhythm, inducing sinus bradycardia in resting conditions, which results in increased HRV (Aubert et al., 2003). These findings have been found in young endurance trained athletes across various sport backgrounds such as cycling, canoeing, roller-skating, and volleyball (Dixon, Kamath, McCartney, & Fallen, 1992; Goldsmith, Bigger, Steinman, & Fleiss, 1992; Puig et al., 1993;
Shin, Minamitani, Onishi, Yamazaki, & Lee, 1997). In a sample of high school males between the ages of 14-19 years old, higher levels of physical activity were reflective of lower sympathetic modulation and increased parasympathetic modulation. Thus, the connection between ANS function and the unique context of athletes can begin to be elucidated through the examination of HRV in a healthy population.

2.2.5 Concussion assessment

Within baseline/pre-injury testing paradigms, it is standard to obtain self-reported symptom scores in addition to other standardized measures such as neuropsychological assessments (McCrorry et al., 2017). In the event of a concussion, these results are used to make comparisons with pre-injury scores in guiding return-to-activity decisions. In particular, the value and focus on subjective symptom reporting has recently been debated (Balasundaram, Athens, Schneiders, McCrorry, & Sullivan, 2016; Schatz, Moser, Solomon, Ott, & Karpf, 2012). Many studies have reported the presence of concussion-like symptoms in healthy (non-concussed) individuals (Gouvier, Uddo-Crane, & Brown, 1988; Hunt, Paniccia, Reed, & Keightley, 2016; Iverson & Lange, 2003; Sady, Vaughan, & Gioia, 2014). For example, in a cohort study of healthy child and youth athletes, Hunt et al. (2016) found that fatigue was reported by more than half of the participants, nervousness was reported by 32% of youth girls, and 25% of the entire youth sample reported headaches, drowsiness and difficulty concentrating. Another study conducted by Balasundaram et al. (2016) illustrated that considerable individual variability in symptoms scores were reported over a 7-day period. Taken together, it is evident that concussion-like symptoms are non-specific; they are likely influenced by a confluence of personal and psychological factors such as school course load, emotional distress and sport seasonality (Chan, 2001). Interactions between the ANS and the heart regulate cardiac activity in response to stimuli such as exercise, environmental stress and emotional changes (XiaoLin, 2014). Given that these stimuli can be manifested by non-specific concussion-like symptoms, exploring the relationship between subjective concussion-like symptoms and HRV can provide specific information on the domains of physical, cognitive, emotional and fatigue symptoms experienced daily within a healthy youth population. The use of HRV can act to corroborate traditionally used clinical measures (subjective concussion symptoms) and provide novel physiological information (objective HRV) on understanding the post-concussion trajectory.
In summary, the exploration of ANS function in the context of development, sex and concussion-like symptoms in a sample of youth athletes is warranted. The objectives of this study are the following: (1) to explore the effect of age and sex on HRV in youth athletes; and (2) evaluate the relationship between HRV and concussion-like symptoms, and more specifically across physical, cognitive, emotional and fatigue domains.

2.3 Methods

Ethics approval was received from the Holland Bloorview Research Ethics Board at Holland Bloorview Kids Rehabilitation Hospital. All participants and their parents provided informed consent prior to their participation in this study (see Appendix 1 for consent form).

2.3.1 Study design

A cross-sectional study of healthy youth athletes was conducted in which pre-injury/baseline data was collected on demographic (age, sex) and concussion-related factors (concussion-like symptoms, previous history of concussion).

2.3.2 Participants

A convenience sample of 294 youth athletes (ages 13-18 years old) was recruited from local community sport organizations (see Appendix 2 for recruitment flyer). Exclusion criteria were the following: participants with developmental delay, neurological condition, symptomatic from previous concussion, and non-English speaking. While participants were permitted to have a concussion history, they had to be asymptomatic and be fully participating in school and sport at the time of study entry. Participant demographics can be found in Table 2.1.
Table 2.1 Participant demographics

<table>
<thead>
<tr>
<th>Variable</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age $M(SD)$</td>
<td>14.22 (1.21)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>128 (43.5%)</td>
</tr>
<tr>
<td>Females</td>
<td>166 (56.5%)</td>
</tr>
<tr>
<td>History of Concussion</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>85 (29%)</td>
</tr>
<tr>
<td>One</td>
<td>57 (19.5%)</td>
</tr>
<tr>
<td>Two-Three</td>
<td>27 (9.2%)</td>
</tr>
<tr>
<td>Four</td>
<td>1 (0.3%)</td>
</tr>
<tr>
<td>Level of Competition</td>
<td></td>
</tr>
<tr>
<td>Competitive</td>
<td>249 (84.6%)</td>
</tr>
<tr>
<td>House league</td>
<td>17 (5.7%)</td>
</tr>
<tr>
<td>Recreation</td>
<td>8 (2.7%)</td>
</tr>
</tbody>
</table>

2.3.3 Measures

2.3.3.1 Demographic collection form

Age, sex and concussion history (i.e., number of previous concussions) were collected using a demographic collection form administered by research personnel. Level of competition (e.g., representative, house-league or recreational) was also collected, and primary sport (defined as the sport they played for the longest duration and at the highest level of competition) was also collected. Please see Appendix 3 for the demographic collection form.

2.3.3.2 Post-concussion symptom inventory (PCSI)

Concussion-like baseline symptoms were collected using the PCSI, as part of a baseline/pre-injury assessment protocol. The PCSI is a self-report symptom assessment scale designed for children and adolescents to assess post-concussion symptoms. The PCSI is a 22-item self-report questionnaire used for youth ages 13-18 years; it has a seven point rating scale from 0 to 6, capturing severity of symptoms (0= ‘not a problem’, 3= ‘somewhat of a problem’, and 6= ‘severe problem’). Both total score (sum of all symptom ratings) and domain score were derived. Symptoms within each domain include, but are not limited to: physical domain (e.g. headache, dizziness, blurred vision); cognitive domain (e.g. trouble concentrating, confused, mentally foggy); emotional domain (e.g. sad, irritable, nervous); and, fatigue domain (e.g. fatigue, drowsiness). The PCSI has been found to have good validity and reliability amongst this age
group (Sady et al., 2014). Internal consistency has been found to range from 0.79-0.93 for the subscales and 0.94 for the total symptom score (Sady et al., 2014). Please see Appendix 4 for the PCSI tool.

2.3.3.3 Heart rate variability (HRV)

The parameters of HRV are obtained non-invasively by calculating the R to R wave interval of the heart via the QRS complex. In order to have sufficient time resolution, a sampling rate of at least 250Hz to 1000Hz (time resolution of 1ms) is recommended (Aubert et al., 2003). This is in line with the Polar RS800CX sampling rate of 1000Hz. Please see Appendix 5 for the Polar technology specifications. The Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology recordings ([Task force], 1996) provides guidelines on the measurement and analysis of HRV. There are two types of linear analysis of HRV, which are time- and frequency domain measures. Time domain analysis is calculated on the basis of RR intervals over time. One subcategory is derived from the RR intervals with the use of means and standard deviations in milliseconds of the interval (e.g. SDNN). The second subcategory of time domain variables is derived from differences between adjacent RR intervals, and is primarily vagally mediated (Faulkner et al., 2003). PNN50 is the proportion of the total RR intervals that have differences of successive RR intervals greater than 50 milliseconds. RMSSD is the square root of the mean squared differences of successive RR intervals. Time domain variables were selected for analysis as they are easily computed and have been shown to be highly correlated with HF power, a measure of parasympathetic activity (Aubert et al., 2003).

Frequency domain measures are computed via power spectral analysis, and addresses the limitation of time domain variables in being unable to discriminate between the parasympathetic and sympathetic branches of the ANS (Aubert et al., 2003). Power spectral analysis uses a computationally efficient Fast Fourier transformation to examine different variations in RR intervals. Here, the heart rate signal is decomposed into its sinusoidal components; this enables the ability to plot the power of each component as a function of its frequency, in defined frequency regions (Task Force, 1996). Fluctuations in RR interval widths are transformed into a frequency waveform that captures periodic oscillations in sympathetic and parasympathetic function. Set out by the Task Force, the frequency bandwidths are characterized: HF (0.15-0.4
Hz); LF (0.04-0.15 Hz). Table 2.2 provides a definition for the time and frequency domain measures used in this study.

**Table 2.2 Definition of time and frequency domain HRV variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDNN</td>
<td>Milliseconds (ms)</td>
<td>Standard deviation of all RR intervals</td>
</tr>
<tr>
<td>RMSSD</td>
<td>Milliseconds (ms)</td>
<td>Root mean square of successive differences between RR intervals</td>
</tr>
<tr>
<td>pNN50</td>
<td>Percentage (%)</td>
<td>Percentage of adjacent RR intervals that differ from each other by more than 50ms</td>
</tr>
<tr>
<td>HF</td>
<td>Milliseconds squared (ms$^2$)</td>
<td>Power in the high frequency range (0.15-0.4 Hz)</td>
</tr>
<tr>
<td>Total Power</td>
<td>Milliseconds squared (ms$^2$)</td>
<td>The variance of all RR intervals</td>
</tr>
</tbody>
</table>

### 2.4 Procedure

Upon receiving their informed consent, all participants completed a baseline/pre-injury assessment. This assessment included the collection of demographic information (age, sex, concussion history [yes/no], number of previous concussions, level of competition in sport played). A 24-hour HRV recording was collected via the Polar RS800CX watch and chest strap (RS800cx; Polar Electro, Kemple, Finland). In accordance with the Task Force (1996), HRV was collected over 24 hours during normal daily routine. Each participant was assisted by research personnel to adjust the heart strap and ensure the sensor was placed on the sternum. Due to the group-based testing environment of this large baseline study, there was not a consistent start time across all individuals. Based on sport team availability and school schedules, the start time varied between morning hours on the weekend and evening hours on the weekday. All participants were instructed to carry out their usual daily activities, with the exception of removing the device (and putting it back on) if they went swimming or played a contact sport. Participants were not controlled in terms of the time they decided to sleep and wake-up. Please see Appendix 6 for the instruction sheet provided to participants. To address this limitation, the variable “Max HRV time” was created to capture the 5-minute window frame that the highest HRV value occurred, with the hypothesis that it would reflect a “sleep period” within the 24-hour recording (i.e. highest parasympathetic activity occurs during sleep; Kim, Yoon, & Cho, 2014). This variable was accounted for in the statistical analysis.
2.4.1 Data analysis

2.4.1.1 HRV analysis

The RHRV program, via R statistical programming (R Core Team, 2013) was used to compute time and frequency domain variables. For purposes of signal processing, it is crucial that the signals are corrected for ectopic and missed beats (Eckberg & Fritsch, 1991; Kamath & Fallen, 1993). The automatic removal of spurious points was performed by the FilterNIHR function. First, this function creates an algorithm and uses an adaptive threshold to reject beats whose value exceeds the cumulative mean threshold. Second, this function replaces beats by a mean combination of preceding and following beats, creating RR intervals appropriate for analyses; the filter was set to a minimum of 25 beats per minute and a maximum of 200 beats per minute. For computation of the spectral components of the RR interval, the InterprolatedNIHR function was employed (4Hz). Window frames were 300 seconds, 50% overlap (please see Appendix 7 for the RHRV script). Duration of the recording influences many HRV indices, thus recordings that were <14 hours and were not continuous recordings were excluded (Aubert et al., 2003). The authors did not examine LF within this study as considerable controversy on the usefulness of this measure has been documented. For example, Goldstein, Bentho, Park, & Sharabi (2011) stated that LF likely isn’t representative of sympathetic autonomic modulation. Similarly, Billman (2013) highlighted LF’s exceedingly poor relationship to sympathetic nerve activation, resulting in challenges delineating the physiological basis of this measure. As such, it would be challenging to interpret the mechanisms driving change in an already exploratory study.

2.4.1.2 Data analysis

Descriptive analyses (mean, SD, range, percentiles) were generated for all HRV variables, and stratified by sex. Linear regression analyses were performed to investigate the effects of age, sex and concussion-like symptoms on HRV in healthy youth athletes. The independent variables were age, sex and PCSI physical, cognitive, emotional, and fatigue domains. The dependent variables were time (i.e., SDNN, RMSSD, pNN50) and frequency domain (i.e., HF, total power) measures of HRV. The “Max HRV Total Power” variable was also included in this analysis to account for the variability in the start/stop time. Visual inspection of the dependent variable (i.e. HRV) indicated values outside the acceptable range of skewness (between -1 and 1) and kurtosis (near the value of 3). Thus, logarithmic transformations were applied to these variables to
enhance statistical inference from the models. These transformations are appropriate based on data skewness and is in line with the analysis approach in the field of HRV in youth (Jarrin et al., 2015). Here, all diagnostic tests indicated good modeling, meeting all model assumptions; constant error variance, no significant outliers, outcome variable is linearly related to the predictors, and the predictors are not linearly dependent and nor do they display multicollinearity. R statistical programming package (R Core Team, 2013) was used for all analyses. Level of statistical significance was set to $p<0.05$.

2.5 Results

The sample in this study consisted of 294 youth between the ages of 13-18 ($M = 14.22$ years, $SD = 1.21$) years old (female=166 [56.5%], male=128 [43.5%]). The majority of athletes played their primary sport at a high level of competition; 84% representative/competitive; 5.7% house league; 2.7% recreation (7.4% did not report level of competition). In terms of sport distribution, 62.5% played hockey, and 18.7% played soccer. The remaining sports were composed of various individual (10.2%; e.g. running, swimming, skiing) and group (4%; e.g. baseball, basketball, volleyball) sports. Youth participants also reported their exposure to sports on a weekly basis ($M = 3.57$ times per week, $SD = 1.15$, $min = 1$, $max = 10$). There were no significant age or sex differences between males and females. The majority of the sample (71%) had no previous history of concussion. Neither sex nor age was significantly related to previous concussion history or number of previous concussions. The majority of youth athletes (78.2%) endorsed at least one symptom on the PSCI; 42.5% endorsed physical symptoms, 37.8% endorsed cognitive symptoms, 61.9% endorsed fatigue symptoms. Participant demographics are presented in Table 2.1. Of the total 294 participants within this study, 147 participants had heart rate recordings which encountered multiple and sporadic start and stop times. Based on methodology recommendations and the RHRV computing backdrop, these were not sound to use for analysis in variables that required a consistent time series (Garcia, Otero, Presedo, & Vila, 2013). Regarding “Max HRV Time”, $M = 3:02$AM, $SD = 1$ hour, 55 minutes, $min = 1:46$AM, $max = 6:55$AM. Descriptive statistics on HRV variables are presented in Tables 2.3 and 2.4 (stratified by sex).
Table 2.3. Descriptive statistics of HRV variables for males

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean (SD)</th>
<th>Range</th>
<th>25th percentile</th>
<th>50th percentile</th>
<th>75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDNN (ms)</td>
<td>128</td>
<td>193.33 (58.87)</td>
<td>88.81-445.82</td>
<td>149.97</td>
<td>186.64</td>
<td>222.79</td>
</tr>
<tr>
<td>RMSSD (ms)</td>
<td>128</td>
<td>68.59 (32.37)</td>
<td>20.31-183.30</td>
<td>44.91</td>
<td>59.65</td>
<td>89.82</td>
</tr>
<tr>
<td>pNN50 (%)</td>
<td>128</td>
<td>26.20 (13.90)</td>
<td>1.93-56.39</td>
<td>14.86</td>
<td>24.31</td>
<td>37.31</td>
</tr>
<tr>
<td>HF (ms²)*</td>
<td>61</td>
<td>444.06 (284.63)</td>
<td>42.45-1113.41</td>
<td>207.21</td>
<td>372.05</td>
<td>684.97</td>
</tr>
<tr>
<td>Total Power (ms²)*</td>
<td>61</td>
<td>3314.24 (1681.27)</td>
<td>781.00-10310</td>
<td>2096.95</td>
<td>3020.03</td>
<td>4096.08</td>
</tr>
</tbody>
</table>

Table 2.4. Descriptive statistics of HRV variables for females

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean (SD)</th>
<th>Range</th>
<th>25th percentile</th>
<th>50th percentile</th>
<th>75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDNN (ms)</td>
<td>166</td>
<td>177.91 (52.89)</td>
<td>77.16-502.95</td>
<td>145.26</td>
<td>170.40</td>
<td>200.42</td>
</tr>
<tr>
<td>RMSSD (ms)</td>
<td>166</td>
<td>65.65 (28.58)</td>
<td>21.87-156.93</td>
<td>44.68</td>
<td>61.20</td>
<td>78.33</td>
</tr>
<tr>
<td>pNN50 (%)</td>
<td>166</td>
<td>25.28 (12.32)</td>
<td>0.93-54.68</td>
<td>15.99</td>
<td>24.51</td>
<td>32.84</td>
</tr>
<tr>
<td>HF (ms²)*</td>
<td>86</td>
<td>307.91 (306.49)</td>
<td>61.64-2324.95</td>
<td>175.08</td>
<td>283.48</td>
<td>495.08</td>
</tr>
<tr>
<td>Total Power (ms²)*</td>
<td>86</td>
<td>2574.99 (1660.58)</td>
<td>944.00-7305</td>
<td>1611.71</td>
<td>2455.76</td>
<td>3272.76</td>
</tr>
</tbody>
</table>

Note: “*” denotes a smaller N based on the inability to analyze those participants (N=147) who had sporadic and multiple start and stop times within the 24-hour recording. According to rigorous analysis methodology, it is not sound to link multiple recordings within one larger recording for the purpose of deriving frequency domain variables (RHRV, R Core Programming, 2013).

Max HRV Total Power. A linear regression was performed on Max HRV total power. Demographic factors (age, sex) were not significant in this model. Concussion-like factors (physical, cognitive, emotional and fatigue domains; concussion history) were also not significant in this model.

SDNN. A linear regression was performed on log (SDNN). Sex had a significant main effect whereby females had lower SDNN compared to males (B= -0.071, SE= 0.033, p = 0.03). Age was also significant (B= 0.031, SE= 0.013, p = 0.023) in predicting SDNN, whereby older participants had higher SDNN compared to younger participants. Regarding concussion-like symptoms, the cognitive domain was the only domain demonstrating a significant effect (B= -0.021, SE= 0.009, p = 0.02). Here, there was a negative relationship whereby youth who
endorsed more cognitive symptoms, had lower SDNN (Figure 2.1). Physical, emotional and fatigue domains as well as previous concussion history were not significant in this model (Table 2.5).

**RMSSD.** A linear regression was performed with non-transformed RMSSD. Age and sex did not have significant main effects within this model. Concussion-like symptoms in the cognitive domain had a main effect on RMSSD ($B=-2.195$, $SE=1.00$, $p=0.03$). A negative relationship was present whereby youth who reported more cognitive symptoms, had lower RMSSD (Figure 2.1). Physical, emotional and fatigue domains as well as previous concussion history were not significant in this model (Table 2.5).

**pNN50.** A linear regression was performed on the non-transformed pNN50. This was modeled differently from the above measures and a best-fit model was derived from including an interaction term and examining the PCSI total score (rather than the domain-specific variables). Age and sex did not have a significant effect on pNN50. The notable finding in this model was a significant interaction effect between PCSI total score and pNN50 as a function of sex ($B=0.424$, $SE=0.211$, $p=0.04$). Here, the relationship between PCSI total score and sex was present in those who did not have a previous history of concussion (Figure 2.1). In females with no previous history of concussion, there was a positive association between PCSI total score and pNN50 whereby, increased concussion-like symptom reporting was associated with increased pNN50. The opposite was found in males with no previous history of concussion, whereby increased concussion-like symptom reporting was associated with decreased pNN50 (Table 2.5).
Figure 2.1. (A) Scatterplot with linear line of best fit depicting relationship between cognitive domain symptoms on PCSI and time-domain HRV variables (log [SDNN], RMSSD). (B) Interaction effect plot, depicting the relationship between PCSI total score by previous history of concussion as a function of sex (male/female) on pNN50.
HF. A linear regression was performed on the non-transformed HF. While age did not have a significant effect, sex did have a main effect on HF ($B = -153.73$, $SE = 64.71$, $p = 0.019$), whereby females had lower HF compared to males. The physical, cognitive, emotional and fatigue domains of the PCSI as well as previous concussion history were not significant in this model (Table 2.5).

Total Power. A linear regression was performed on log (total power). Sex had a significant main effect on total power ($B = -0.203$, $SE = 0.08$, $p = 0.01$), whereby females had lower total power compared to males. Age, concussion-like domains, and previous history of concussion were not significant in this model (Table 2.5).

**Table 2.5 Linear regression model estimates of demographic and concussion-related factors**

<table>
<thead>
<tr>
<th>HRV Variable</th>
<th>Sex</th>
<th>Age</th>
<th>PCSI Physical</th>
<th>PCSI Cognitive</th>
<th>PCSI Emotional</th>
<th>PCSI Fatigue</th>
<th>Previous Concussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>log (SDNN)</td>
<td>-0.071 (0.03)*</td>
<td>0.031 (0.01)*</td>
<td>-0.013 (0.01)</td>
<td>-0.021 (0.009)*</td>
<td>0.015 (0.01)</td>
<td>0.015 (0.01)</td>
<td>0.061 (0.04)</td>
</tr>
<tr>
<td>RMSSD</td>
<td>-2.746 (3.60)</td>
<td>-0.133 (1.46)</td>
<td>-0.991 (1.13)</td>
<td>-2.195 (1.00)*</td>
<td>1.429 (1.43)</td>
<td>1.097 (1.58)</td>
<td>6.585 (3.90)</td>
</tr>
<tr>
<td>pNN50$^a$</td>
<td>-2.676 (1.85)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>2.997 (1.67)</td>
</tr>
<tr>
<td>HF</td>
<td>-153.73 (64.71)*</td>
<td>-5.98 (20.33)</td>
<td>-31.41 (17.38)</td>
<td>-11.31 (14.99)</td>
<td>-17.77 (23.89)</td>
<td>4.57 (23.74)</td>
<td>43.47 (55.09)$^a$</td>
</tr>
<tr>
<td>log (Total Power)</td>
<td>-0.203 (0.08)*</td>
<td>0.017 (0.03)</td>
<td>-0.035 (0.03)</td>
<td>-0.021 (0.02)</td>
<td>0.018 (0.04)</td>
<td>0.037 (0.03)</td>
<td>0.110 (0.09)</td>
</tr>
</tbody>
</table>

Note: “*” denotes a significant p-value < 0.05. “$^a$” denotes the uniqueness of the pNN50 model.

Level of fit indicated a removal of age as a factor and removal of each PCSI domain. Rather, PSCI total score enhanced the fit of the model and is described within the results section.

### 2.6 Discussion

The purpose of this study was to examine the effect of age, sex and concussion-like symptoms on a measure of cardiac autonomic function (HRV). To date, this area of research has been limited by: (1) the lack of focus on the youth population, compared to studies on children or adults; (2) the specific exploration of demographic trends within an athlete population; and (3) the corroboration of a novel physiological measure with traditionally used clinical measures. The Task Force (1996) has specific standards for the measurement and physiological interpretation of HRV. A limitation of these standards is the small sample and the factors that are not accounted for such as age, sex and environment factors. To the author’s knowledge, this study is one of the
first to examine HRV in the context of demographic and concussion-like symptoms in a large sample (N=294) of youth athletes. This study found significant effects of sex and age across HRV measures as well as the impact of everyday cognitive symptoms on HRV. Previous history of concussion, while accounted for, did not appear to markedly effect HRV across all measures.

2.6.1 Age effects

This study found a developmental effect on HRV in one (SDNN) of the five HRV variables examined whereby older participants had higher SDNN compared to younger athletes. While age-related trends in HRV are likely related to age-related changes in heart rate (Fleming et al., 2011), these developmental trends were not found in other measures of HRV. However, when comparing mean HRV values to those found in a systematic review comparing athletic versus non-athletic adults, the youth values found in this study were all markedly higher (SDNN, RMSSD, HF) than those reported in the review (da Silva, de Oliveira, Silveira, Mello, & Deslandes, 2015). Fukuba et al. (2009) explored HRV characteristics of pre- and post-adolescent Japanese individuals between the ages of 8 and 20 years and found no effect of age on parasympathetic and sympathetic indices. Authors concluded that the control of the ANS during this period of adolescence and young adulthood may be comparable with that seen in adulthood. Further, cardiac autonomic modulation may not develop until approximately 7-8 years old and stabilize throughout adolescence (Fukuba et al., 2009). This mechanism has been emphasized as a stabilization of sympathovagal balance, noted by increased cholinergic and decreased adrenergic modulation of HRV (Massin & von Bernuth, 1997). Similarly, Seifert et al. (2014) found related results in comparing a group of children under the age of 11 years to a group of children over the age of 11 years. Significant trends of HRV in the group of children under the age of 11 years were found (i.e., HRV decreased with increasing age). However, these were not present in the group over the age of 11 years (Seifert et al., 2014). Given that (1) the sample in this study was comprised of 13-18 year old athletes and, (2) 17-18 year olds only made up 5.1% of the total sample, the high performance athletic status and age range may not have been sensitive enough to capture developmental change. Here, it is unclear if SDNN is a more sensitive variable to detecting change compared to the other HRV variables or if developmental trends are in fact experienced differently for athletes.
2.6.2 Sex effects

The current study found consistent sex differences across both time (i.e., SDNN) and frequency domain HRV measures (i.e., HF, total power), whereby females displayed decreased HRV compared to males. These results are mirrored in a recent meta-analysis on sex differences in HRV across the life span, which found that females have less variability in the time-domain measures, and lower total power (Koenig & Thayer, 2016). However, the meta-analysis also found that females have higher HF power compared to males, which is contrary to the findings of the current study. This might have occurred for two reasons. First, the tendency for this sex-related difference in HF may be linked to autonomic neural maturation as adolescents’ transition to young adulthood. Our findings are consistent with adolescent literature, which have shown that boys displayed higher HRV in measures that reflect parasympathetic activity (SDNN, RMSSD, pNN50, HF; Henje Blom, Olsson, Serlachius, Ericson, & Ingvar, 2009; Reed, Warburton, Whitney, & McKay, 2006; Silvetti, Drago, & Ragonese, 2001). These results are not surprising given that girls typically experience puberty two years prior to boys (Rogol, Clark, & Roemmich, 2000). Here, pre-pubertal hormonal changes such as estrogen and progesterone as well as substantial changes of hormonal levels during induction of ovulation play a role in driving change in HRV (i.e., lowering HRV; Erzat Toprak, 2013). Thus, the timing of pubertal development may coincide with the emergence and maturation of neural autonomic mechanisms (Chen et al., 2012; Faulkner et al., 2003; Lenard, 2004). Second, sex differences found in this study may be linked to athleticism; boys in this age range may engage in more physical training thus increasing their HRV compared to girls (Sharma, 2015). While there were no significant differences between males and females in the level of sport exposure within this study (males: $M=3.45$, $SD=1.04$; females: $M=3.66$, $SD=1.22$), it is unclear how the level of intensity and duration of sport exposure differed. Given that baseline sex differences in HRV exist in healthy youth, it can be hypothesized that ANS vulnerabilities occurring within this developmental stage, may potentially explain the role that sex plays in concussion recovery where it has been found that females report more concussions (Covassin, Swanik, & Sachs, 2003), experience a greater severity of symptoms and a protracted recovery compared to males (Zemek et al., 2016). Future research on how these sex differences manifest following a concussion is warranted.
2.6.3 Concussion-like symptoms

There has been an emergent focus on examining baseline/pre-injury values of clinical measures used to guide return-to-activity decision-making in athletes. Across a multitude of studies (Hunt et al., 2016; Iverson & Lange, 2003; Sady et al., 2014), it has become evident that there may be significant overlap in daily variations of concussion-like symptoms with those experienced by an injured population. As such, the reliance on using subjective self-report following a concussion may be difficult to decipher. It is also important to note that subjective symptom reporting is problematic in athletic populations who may be prone to inaccurate reporting due to fear of a prolonged return-to-play process (Lovell et al., 2002). This study explored a novel physiological measure (HRV) in the context of a traditionally used subjective measure (PCSI) and found that endorsing cognitive symptoms was reflected in lower HRV.

Cortico-subcortical networks, which regulate harmony between the sympathetic and parasympathetic branches of the ANS, structurally and functionally link to cognitively-related processes (Thayer & Sternberg, 2006). Within the domain of cognitive symptoms experienced day-to-day, reported difficulties with memory, concentration, confusion, and slower mental processing can feedback to the ANS as a form of physiological stress, causing changes in cardiovascular regulation. A recent meta-analysis on the effects of acute mental stress in healthy adults revealed significantly lower HRV in those who experience more stress on tasks of computer work, arithmetic, and academic examination (Castaldo et al., 2015); authors stated a potential autonomic balance shift towards sympathetic activation and parasympathetic withdrawal. While it is not surprising that high-performing youth athletes experience variations in concussion-like symptoms (Hunt et al., 2016), it is important to consider the potential post-concussion implications of these findings. Clinically, an understanding of the factors that drive change in neurophysiological function can act to corroborate changes seen across subjective clinical measures (symptom reporting). Here, baseline/pre-injury trends in cognitive symptoms and HRV can contextualize and inform post-concussion comparisons. It may be that youth athletes who report high levels of cognitive symptoms and display decreased HRV at baseline have a protracted recovery in the event of a concussion compared to those who experience fewer cognitive symptoms on a daily basis. This study provides a foundation to that inquiry and demonstrates the presence of a physiological signal in daily forms of cognitive stress.
Endorsing symptoms in physical, emotional and fatigue domains did not reveal any effects in the current study. In non-athlete populations of healthy adolescents, a scoping review revealed relationships between daily emotional symptoms of anxiousness, nervousness and sadness and decreased HRV; it is hypothesized that the ability to regulate emotions relates to ANS flexibility and adaptability in the face of life stressors (Paniccia et al., 2017). However, being a healthy youth athlete may be a protective factor in these concussion-like domains. For example, youth athletes, compared to non-athletes have been shown to have better psychosocial functioning, emotional wellbeing, self-efficacy, and psychological resilience (Eime, Young, Harvey, Charity, & Payne, 2013). It may be plausible that daily physical symptoms are mitigated by sport participation as well. However, it is worth noting that the PCSI is not a comprehensive assessment on each of these domains and expansion of these domains within targeted clinical assessments is warranted within this population.

Finally, the interaction between total symptom score on HRV as a function of sex is noteworthy; in youth athletes with no history of concussion, females who reported more total concussion-like symptoms displayed increased HRV, whereas males who reported more total symptoms displayed decreased HRV. This finding is in line with concussion research which revealed a suppression of LF power in males, associated with mood disturbances, even following symptom resolution (Hutchison et al., 2016). These sex differences are also in line with literature in the field of psychophysiology which state that in the context of stress, females may be more likely to “tend-and-befriend”, seeking out a support network and resources for coping (Turton & Campbell, 2007). Afferent ANS pathways have demonstrated the release of oxytocin via oxytocin neurons to buffer stress and serves to reduce the impact of stressful events; this feedback loop has been implicated in inducing bradycardia (lowered heart rate) which in turn increases HRV (Higa, Mori, Viana, Morris, & Michelini, 2002). Conversely, males may employ the “fight-or-flight” reaction in response to stress, increasing sympathetic activity and decreased HRV (Turton & Campbell, 2007). While the ability to cope with concussion-like symptoms was not captured in this study, the constructs of self-management and self-regulation would be key to consider in future research.
2.7 Limitations

This study is not without limitations. First, the HRV methodology employed a 24-hour recording, which was taken during normal, everyday conditions. While this approach has been deemed ecologically valid (Bornas, Balle, De la Torre-Luque, Fiol-Veny, & Llabres, 2015), interpretations of change in HRV can be limited by other factors such as frequency and intensity of physical activity. Levels of physical activity likely differ across age and this may have contributed to the large variance seen in HRV variables. The training phase of each youth athlete was not captured in this study; thus, it is possible that some youth were in a competitive phase, training phase or even off-season. Associations of HRV have been described with physical activity in which increased participation in physical activity was associated with increased HRV (Buchheit, Platat, Oujaa, & Simon, 2007; Gutin et al., 2005; Nagai & Moritani, 2003). Within an adolescent sample of boys aged 14-19 years old, higher reported levels of physical activity was positively associated with both time and frequency domain HRV measures (Farah, Barros, Balagopal, & Ritti-Dias, 2014). On the other hand, a previous study using controlled conditions (Davignon et al., 1980) revealed that the variance of the average heart rate was also large across age groups; this finding was also replicated in a review on heart rate in adolescents (Fleming et al., 2011). Thus, it is unclear if the large variance reflects the differences of the individual characteristics of cardiovascular control rather than the differences of activity. Restrictions on physical activity in this study were not feasible or appropriate for long-term recordings, given the diverse activity repertoires of youth (school, sport, extracurricular activity). However, given that the sample was predominantly representative/high-performing athletes, there is some homogeneity in this sample. These youth athletes likely engage in moderate to vigorous forms of physical activity on a regular basis, and it is hypothesized that this group of representative athletes would demonstrate higher cardiorespiratory fitness and specific patterns of change in HRV. It is worth noting that the limitation in not accounting for physical activity does mirror the current state of the literature (Koenig & Thayer, 2016) and may be related to the feasibility of collecting this information when it is not the main objective of the study. To address this gap, future exploration could include the concurrent collection of HRV and actigraphy technology to capture the type, frequency, and intensity of physical activity.

Second, development was assumed to be captured by age; while these two variables are highly correlated, more rigorous evaluation such as Tanner’s stage (Tanner & Whitehouse, 1976) may
have yielded a more sensitive means to capture developmental trends in ANS function (Faulkner et al., 2003). This recommendation is likely useful given the variation in autonomic modulation occurring after puberty (Tanaka et al., 2000). However, due to the fact that youth athletes were in the presence of other youth during the baseline/pre-injury testing protocol, it was not feasible to collect highly sensitive information without the risk of disclosing private information. Further, a potentially confounding effect may have been menstruation cycle in females. Studies investigating the effects of the menstrual cycle on cardiac autonomic function have stated that regulation of autonomic tone is modified during the menstrual cycle, in which the alteration of ovarian hormones might be responsible for changes seen in cardiac autonomic activity (Saeki, Atogami, Takahashi, & Yoshizawa, 1997; Sato, Miyake, Akatsu, & Kumashiro, 1995). Based on the age range of this sample (13-18 years old), it is unclear how the menstrual cycle may or may not have played a role in symptom reporting or in HRV changes. Future study capturing stage of development in addition to time period of menstrual cycle would likely contribute to a more robust understanding of developmental variations in ANS function.

### 2.8 Conclusion

This study explored the influence of demographic factors such as age and sex as well as concussion-like symptoms on HRV. Findings indicate the presence of variability in reporting concussion-like symptoms in a healthy, non-concussed sample of youth athletes. Here, youth athletes who reported more cognitive symptoms had lower HRV. It is unclear if this relationship would extend to a concussed population. However, this finding is a foundational first step in exploring a novel physiological measure in the context of a traditional, subjective measure (PCSI) used in the clinical assessment of youth athletes. Sex differences were consistent across HRV measures revealing that females have lower HRV compared to males. Interestingly, the relationship between concussion-like symptom reporting and HRV differed between males and females (with no previous concussion), and assessments of coping and self-management may provide additional information at elucidating this difference.
2.9 References


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Chapter 3
Heart Rate Variability following Youth Concussion: How do Autonomic Regulation and Concussion Symptoms Differ Over Time Post-Injury?

3 Overview

This chapter presents a prospective, longitudinal, matched-control study in which the recovery trajectory of concussion in youth athletes is depicted through HRV. Here, the factor of time across days post injury illustrates the non-linear trajectory of a physiological measure (HRV), in the context of a traditional subjective measure (self-report of symptoms). This chapter presents preliminary data on the relationship between HRV and post-concussion symptom domains (physical, cognitive, emotional, fatigue). This chapter explored the physiological mechanisms (HRV) at play following a psychosocial stressor (concussion), and health outcome (days post injury).

An abbreviated form of this chapter is being prepared for submission to The British Journal of Sport Medicine. This journal provides a forum for the dissemination of research centred on athletics and novel topics, which include both the clinical and physiological recovery of concussion. The most recent Consensus Statement on Concussion in Sport was published within this journal, highlighting the need for the research presented within this chapter.

3.1 Abstract

Background: In the assessment of concussion, monitoring the resolution of subjective symptoms has been a key anchor in gauging when an athlete is ready to return to activity. Youth athletes may minimize their symptom presentation due to high motivation to return to activity. Thus, objective indicators are needed to corroborate changes in traditionally used clinical measures. Heart rate variability (HRV) is a non-invasive physiological measure that captures the balanced interplay between the parasympathetic and sympathetic branches of the autonomic nervous system. The study of HRV in athletes has begun to emerge when examining the adult varsity population, however, there is little known on how concussion impacts HRV in youth athletes. The objectives of the current study were to: (1) explore the effect of concussion on
HRV across days post-injury in youth athletes aged 13-18 years old; (2) examine the relationship between post-concussion symptom domains (physical, cognitive, fatigue and emotional) on HRV; and (3) investigate the effect of having a concussion on HRV compared to healthy age- and sex-matched controls. **Method:** Prospective, longitudinal, case-control study (N=44). This study was comprised of 29 concussed athletes between the ages of 13 to 18 years old (21 females, 8 males; age: 15 years old [+1.48], and 15 age- and sex-matched controls). All participants completed pre-season baseline testing, which included the collection of demographic information (age, sex, concussion history), self-reported concussion symptoms (Post-Concussion Symptom Inventory [PCSI]), and a long-term heart rate recording. Domain scores from the PCSI were computed for physical, cognitive, emotional and fatigue domains. Heart rate was collected using the Polar RS800CX system for a duration of 24 hours. For concussed participants, the PCSI and HRV were collected weekly while the participant was symptomatic and then 1, 3, and 6 months following symptom resolution. Control participants followed the same repeated measures protocol. **Outcome Measures:** HRV was the primary outcome of interest and included time (SDNN, RMSSD, pNN50) and frequency (HF, HFnu) domain measures. Data visualizations and mixed effects modeling, using a random intercept model was used to derive parsimonious models, and pre-injury baseline HRV values were accounted for. **Results:** Days post-injury had a significant main effect on HRV, whereby HRV increased across days post-injury. Concussion symptom domains (physical, cognitive, fatigue and emotional) all had a significant main effect on HRV. Within the concussed group, participants who reported more symptoms had higher HRV and those who reported fewer symptoms had decreased HRV. Visualizations of HRV depict the recovery trajectory as non-linear across time. No significant differences on HRV measures were found between concussed and control participants. Age, sex, pre-injury HRV, and history of concussion were accounted for but not significant in the mixed regression models. **Conclusions:** These preliminary findings highlight the importance of corroborating subjective (self-reported symptoms) measures with objective (HRV) measures in the context of examining clinical and physiological recovery trajectories. Clinically, findings provide the foundation to understand the varied trajectory and relationship between objective physiological measures and subjective symptom reporting.
3.2 Introduction

Sport-related concussion is considered to be among the most complex injuries in sports medicine to diagnose, assess and manage as the clinical signs and symptoms largely reflect a functional rather than a structural injury (McCrory et al., 2017). Defined by the most recent consensus statement on concussion in sport, a concussion is a traumatic brain injury induced by biomechanical forces, which can be caused by a direct blow to the head, or elsewhere on the body transmitting force to the head (McCrory et al., 2017). It is estimated that 4 million children present to emergency departments worldwide with concussion (Aubry et al., 2002; McCrory, 2005; McCrory et al., 2017). More recently, Zemek et al. (2017) revealed that there were approximately 176,000 pediatric visits for concussion in the emergency department in Ontario, with a 4.4 fold increase per 100,000 from 2003-2013.

With respect to youth athletes, this is a significant concern, given that competing in sports places them at a higher risk of sustaining an injury compared to non-athletes (Abaji, Curnier, Moore, & Ellemberg, 2016). Although understudied, a concussion experienced by youth has been noted to have the longest recovery times, compared to children and adults (Leddy, Baker, Haider, Hinds, & Willer, 2017). In pediatric concussion clinic settings, longer recovery times range from 25 to 75 days and 43-75% of patients experience symptoms that last greater than 4 weeks, resulting in persistent concussion symptoms (Ellis et al., 2016).

3.2.1 Assessing recovery following concussion

In the assessment of concussion, well-established protocols have included neuropsychological testing and subjective symptom reporting to gauge clinical recovery (Giza et al., 2013; Harmon et al., 2013; McCrory, 2005; McCrory et al., 2017). Neuropsychological testing has contributed significant clinical value in understanding cognitive recovery over the time course of symptom recovery (Chen et al., 2004; Lax et al., 2015; McCrory et al., 2017; Ptito, Chen, & Johnston, 2007). As well, monitoring the resolution of subjective symptoms has also been a key anchor in gauging when an athlete is ready to return to activity (Bigler, 2008; Hunt, Paniccia, Reed, & Keightley, 2016; Reed et al., 2014). While these methods are routinely used in research and clinical practice, their application to youth athletes in particular, presents with challenges. Firstly, elucidating the etiology of concussion symptoms is difficult because post-concussion symptoms are non-specific (Bigler, 2012; Hunt et al., 2016). They can be found across a variety of clinical
populations, including post-traumatic stress (Bryant & Harvey, 1999), depression and anxiety (Meares et al., 2011), and psychosocial stressors (Iverson & Lange, 2003; Iverson, Lange, & Franzen, 2005; Stancin et al., 2001). Secondly, previous studies have shown that athletes may minimize their symptoms over concerns of delayed return to play (Bailey, Echemendia, & Arnett, 2006; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001), or they lack appropriate knowledge of the symptoms and consequences of concussion (Cournoyer & Tripp, 2014). In alignment with multidisciplinary management views of concussion, the assessment of the athlete should not be a catalogue of concussion symptoms (Ellis, Leddy, & Willer, 2016). Thus, objective physiological measures are needed to disentangle the many factors that play a role in subjective symptom reporting and to elucidate a physiological recovery trajectory that may present differently from a clinical recovery trajectory.

3.2.2 The evolving physiological approach

Concussion has recently been viewed to affect physiological processes including cardiovascular regulation and the reciprocal links between the heart and the brain (McCraty & Shaffer, 2015). Specifically, emerging areas of research are linking concussion to autonomic nervous system (ANS) dysfunction (La Fountaine, Gossett, De Meersman, & Bauman, 2011; La Fountaine, Heffernan, Gossett, Bauman, & De Meersman, 2009). The ANS is responsible for maintaining homeostasis and has been used in the assessment of cardiovascular and central nervous system integration. This interaction results in beat-to-beat variation of heart rate, resulting in HRV. The primary ANS control centre, located in the brainstem, is comprised of the sympathetic and parasympathetic branches, which act reciprocally to promote homeostasis (Leddy et al., 2017). In times of stress, the sympathetic branch mobilizes energy to prepare the body for action while the parasympathetic branch promotes energy restoration. The balance between these two branches are reflected in higher HRV, whereas lower HRV has been indicative of impaired health (Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology [Task Force], 1996). HRV has been established as a non-invasive tool for the exploration of ANS function (Blake, McKay, Meeuwisse, & Emery, 2016; Nunan, Sandercock, & Brodie, 2010; Sandercock & Brodie, 2006), specifically cardiovascular health (Thayer, Yamamoto, & Brosschot, 2010; Vrijkotte, van Doornen, & de Geus, 2000), stress responses (Aubert, Seps, & Beckers, 2003; Vukasović & Gal, 2007), emotional regulation (Paniccia, Paniccia, Thomas, Taha, & Reed, 2017), and cognition (Conder & Conder, 2014).
With respect to traumatic brain injury, HRV has been used to assess autonomic dysfunction across severe, moderate and recently mild traumatic brain injury (Gall, 2004; Gall, Parkhouse, & Goodman, 2004; Hutchison et al., 2017). Within moderate and severe brain injury, significant reductions in HRV have been found (Baguley, Nott, Slewa-Younan, Heriseanu, & Perkes, 2009; Biswas, Scott, Sommerauer, & Luckett, 2000; Goldstein et al., 1996; Goldstein, Toweill, Lai, Sonnenthal, & Kimberly, 1998). Specifically, reduced parasympathetic activity has been associated with poor recovery (Rapenne et al., 2001). It has been postulated that lower HRV reflects an individual’s challenge to adapt and be flexible to their environment (Thayer, Hansen, Saus-Rose, & Johnsen, 2009). In concussion, there may be damage to the primary ANS control centre, which has been supported by white matter neuron damage found in the brainstem following concussion (Polak, Leddy, Dwyer, Willer, & Zivadinov, 2015). While it has been noted that the physiological dysfunction typically resolves within days to weeks after the injury (Giza & Hovda, 2001; McCrea et al., 2003), the physiological resolution does not necessarily correspond with the clinical resolution of symptoms. This study aims to fill that gap by exploring potential physiological changes in HRV, while considering subjective symptom reports along the recovery trajectory.

3.2.3 What is known about concussion and HRV

The exploration of HRV and concussion in sport populations has not been extensive, with few studies investigating the university athlete (Hutchison et al., 2017; Leddy, Kozlowski, Fung, Pendergast, & Willer, 2007; Senthinathan, Mainwaring, & Hutchison, 2017), and no studies examining the youth athlete population. Nonetheless, it is important to summarize these adult findings to provide a foundation for examining the youth population. In a recent prospective matched control study of university athletes, some perturbations in HRV (LFnu, HFnu) were found to persist beyond symptom resolution, which illustrate the potential of prolonged ANS disturbance following concussion (Senthinathan et al., 2017). Similarly, Gall et al. (2004) found that concussed athletes who reported recent symptom resolution still demonstrated abnormal HRV during exercise compared to healthy controls, which may be indicative of the inability to switch between parasympathetic and sympathetic branches for optimal regulation of the body’s needs. This finding was replicated by a recent study, which demonstrated that psychological systems and sleep disturbance following concussion in athletes were resolved at the return-to-play time point; however, ANS disturbances were still present (i.e., decreased HRV), beyond
return-to-play (Hutchison et al., 2017). While these studies do follow-up at discrete clinical time points (symptomatic, asymptomatic and return-to-play), these time points may not provide the opportunity to see the subtle physiological changes that occur between those time intervals. This may skew the findings to reflect a linear increase in HRV across days post injury. It has been cited that more substantial follow-up will be valuable in improving the understanding of the natural history of change in ANS function following concussion (Blake et al., 2016; Hutchison et al., 2017). Further, it is not clear if the same trends between subjective symptom reporting and objective HRV measures would manifest similarly in the youth population. This is a key consideration given that the period of adolescence years might be the most vulnerable time period for having persistent symptoms (McCrory et al., 2017; Zemek et al., 2016). Understanding physiological trajectories of recovery could provide information as a basis for comparison to adults, as well as gauge the specific needs of this population to support continued recovery. The current consensus statement on concussion in sport (McCrory et al., 2017) has identified the following major gaps in assessing the value of neurophysiological measures: (1) lack of longitudinal designs, and (2) careful correlation with clinical measures, with little known on how these trends manifest within a youth population. Thus, this study aims to fill these gaps with the following exploratory research questions:

1. What is the effect of concussion on HRV across days post-injury in youth athletes aged 13-18 years old?
2. What is the relationship between post-concussion symptom domains (physical, cognitive, fatigue and emotional) on HRV?
3. What is the effect of having a concussion on HRV compared to healthy controls?

### 3.3 Methods

Ethics approval was received from the Holland Bloorview Research Ethics Board at Holland Bloorview Kids Rehabilitation Hospital. All participants and their parents provided informed consent prior to their participation in this study (see Appendix 1 for consent form).

#### 3.3.1 Study Design

Prospective, longitudinal, case-control study, with youth athletes between the ages of 13 to 18 years old, in which HRV was collected at baseline and across multiple follow-up time points following concussion.
3.3.2 Participants

A convenience sample of 553 youth (ages 13-18 years old) was recruited from local sport community organizations. Participants were part of a larger pre-injury baseline testing study in Ontario, Canada where they completed a multi-modal assessment consisting of physical (strength and balance), neurocognitive (computerized neuropsychological test), clinical (subjective concussion symptoms) and physiological (HRV) measures. The full multi-modal assessment protocol can be viewed in Reed et al. (2014). The objective of this larger study was to collect baseline values on the measures for post-injury comparisons. This study solely focused on the relationship between subjective concussion symptom reporting and objective HRV measures. Inclusion criteria were the following: male or female youth athlete; ages 13-18 years old. Participants with a diagnosis of developmental delay, neurological condition, cardiac disease, experiencing symptoms from a previous concussion, or non-English speaking were excluded from the study. While participants were permitted to have a concussion history, they had to be asymptomatic and be fully participating in school and sport at the time of study entry.

3.3.3 Measures

3.3.3.1 Demographic collection form

Age, sex and concussion history (i.e., number of previous concussions) were collected using a demographic collection form administered by research personnel (Appendix 3). Type of primary sport (i.e. sport played most often and at the highest level) and level of play (e.g., representative/competitive, house-league or recreational) were also collected. The participant completed this form and research personnel provided instruction and guidance as needed.

3.3.3.2 Acute concussion evaluation (ACE) form

The ACE form is a post-injury questionnaire administered by trained clinicians. It collects information on injury characteristics, symptoms, risk factors for prolonged recovery (e.g., history of migraine), and red flags that would warrant going to an emergency department (Gioia & Collins, 2006). This measure was only used for those participants who sustained a concussion. See Appendix 8 for the ACE tool.
3.3.3.3 Post-Concussion Symptom Inventory (PCSI)

The PCSI is a 22-item self-report questionnaire used to assess post-concussion symptoms with youth ages 13-18 years old (Appendix 4); it has a seven point rating scale from 0 to 6, capturing severity of symptoms (0= ‘not a problem’, 3= ‘somewhat of a problem’, and 6=‘severe problem’). Summed domain scores were derived for the following four domains: physical domain (e.g. headache, dizziness, blurred vision); cognitive domain (e.g. trouble concentrating, confused, mentally foggy); emotional domain (e.g. sad, irritable, nervous); and, fatigue domain (e.g. fatigue, drowsiness). The PCSI has been found to have good validity and reliability amongst this age group (Sady, Vaughan, & Gioia, 2014). Internal consistency has been found to be moderate to strong, with cronbach’s alpha ranging from 0.79-0.93 for the symptom subscales (Sady et al., 2014).

3.3.3.4 Heart rate variability (HRV)

Heart rate recording was obtained from the Polar RS800CX watch and chest strap (RS800CX; Polar Electro, Kemple, Finland). The RR wave interval was calculated from the QRS complex, which was sampled at 1000Hz (time resolution of 1ms), in line with current recommendations (Aubert et al., 2003). The full technical specifications of the RS800CX watch and monitor can be found in Appendix 5. The Task Force (1996) provides guidelines on the measurement and analysis of HRV. Table 3.1 provides a definition of the time and frequency domain measures used in this study. In line with these recommendations, 24-hour recording methodology was suitable to the research objectives of this study, as isolated short-term recordings may not accurately represent autonomic modulations over a period of time (Biswas et al., 2000). It is within the long-term recordings that ANS responses can be evaluated in response to real-world circumstances such as daily normal activities, injury, and the effect of therapeutic interventions which is key for making predictions on prognosis (Kleiger, Stein, & Bigger, 2005). Further, the short-term, 5 minute recording has the limitation in not measuring fluctuation in RR intervals, especially given that HRV responds dynamically to physiologic perturbations. Time domain measures, such as SDNN, have been used in many studies with 24-hour recording methodology as they depend on longer-term recordings to reflect accuracy in deriving their value (Task Force, 1996). Given the exploratory aim of this study and the overarching goal of capturing dynamic change, it was suitable to utilize a recording methodology that reflected the
daily fluctuation in activity repertoire unique to this population. RR Interval data were processed as indicated below, under Data Analysis.

3.4 Procedure

Participants were recruited from various sports team organizations across the Greater Toronto Area via email and recruitment flyers from 2013-2017. The recruitment strategy involved research staff connecting with coaches across various sport organizations via email and recruitment flyers (see Appendix 2 for recruitment flyer). Upon receiving their informed consent, all participants completed a baseline/pre-injury assessment. This assessment included the collection of demographic information (age [years], sex, concussion history [yes/no], number of previous concussions, type of sport and level of competition in their primary sport). All participants completed a baseline testing protocol (Reed et al., 2014) that included the completion of the demographic collection form, PCSI, and participants were fitted with a Polar RS800CX watch and chest strap (RS800CX; Polar Electro, Kempele, Finland). Each participant was assisted by research personnel to adjust the heart rate chest strap and ensure the sensor was placed on the sternum. In accordance with the Task Force (1996), HRV was collected over 24 hours during normal daily routine to reflect variation in real-world circumstances. Due to the group-based testing environment of the larger baseline study, there was not a consistent start time across all individuals. Based on individual availability and school schedules, the start and stop time of the HRV data collection varied. All participants were instructed to carry out their usual daily activities, with the exception of removing the device (and putting it back on) if they went swimming, took a bath or played a contact sport. Participants were not controlled in terms of the time they decided to sleep and wake-up.

Youth athletes who sustained a concussion were instructed to receive a diagnosis from a physician. Within this study, concussion was defined according to the 4th consensus statement on concussion, “a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head; rapid onset of short lived impairment of neurologic function that resolves spontaneously; a graded set of clinical symptoms that may or may not involve loss of consciousness” (McCrory et al., 2009). Concussed participants were then followed by research personnel (with health science backgrounds; occupational therapy, kinesiology); (1) weekly follow-up assessment while symptomatic; (2) 1, 3, and 6 months post-symptom resolution
(asymptomatic). Participants were deemed to be asymptomatic when they self-reported a resolution of concussion symptoms and reported to begin their gradual return to pre-injury functional activities (school, sport, extracurricular activities). The first follow-up included completion of the ACE form by the research personnel, and the PCSI and HRV by the participant. Within this first follow-up, all concussed participants received concussion education on management strategies according to the evidence informed ‘Concussion & You’ Handbook (Reed & Provvidenza, 2014). Here, the following domains of concussion management strategies were addressed: (1) energy conservation; (2) sleep hygiene; (3) hydration and nutrition; and (4) gradual return to school and sport. These domains were re-visited on an as-needed basis during subsequent follow-ups depending on the questions/concerns of the concussed youth athlete. All subsequent follow-up visits included the completion of these measures (except for the ACE form). Age (+/- 6 months) and sex-matched control participants were recruited from the baseline cohort and contacted via email, with an opportunity to decline further communication if they were not interested. For those interested in participating as a control, pre-determined dates were arranged to align with timing of the follow-up visits of their matched concussed participant. The same measures were collected at each follow-up with the exception of the ACE form at the first follow-up visit.

3.4.1 Data Analysis

3.4.1.1 HRV Analysis

There are two types of linear analysis of HRV, which are time and frequency domain measures. Time domain analysis calculates the distance between RR intervals and represents the instantaneous change in heart rate, providing an overall index of HRV (Task Force, 1996). Time domain variables were selected for analysis as they are easily computed and have been shown to be highly correlated with HF power, a measure of parasympathetic activity (Aubert et al., 2003). Frequency domain variables describe the distribution of HRV as a function of frequency using power spectral analysis. Power spectral analysis uses a computationally efficient Fast Fourier transformation to examine variations in RR intervals. Here, the signal is plotted as a function of its frequency, in defined frequency regions (Task Force, 1996). Set out by the Task Force, the frequency bandwidths are characterized: HF (0.15-0.4 Hz); LF (0.04-0.15 Hz). See Table 3.1 for the time and frequency domain measures used in this study.
Table 3.1 HRV variable definitions

<table>
<thead>
<tr>
<th>HRV Measure</th>
<th>Units</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDNN</td>
<td>ms</td>
<td>Total variability, calculated by the standard deviation of interbeat intervals</td>
</tr>
<tr>
<td>RMSSD</td>
<td>ms</td>
<td>Square root of the mean of the squares of the successive differences between adjacent NNs</td>
</tr>
<tr>
<td>pNN50</td>
<td>%</td>
<td>The number of pairs of successive NNs that differ by more than 50 ms, divided by total number of NNs</td>
</tr>
<tr>
<td>HF</td>
<td>ms</td>
<td>Index of parasympathetic influence on heart based on rhythmic respiration cycles; power spectral analysis calculated as high-frequency (0.15–0.40 Hz) band</td>
</tr>
<tr>
<td>HFnu</td>
<td>%</td>
<td>([\text{HF}/(\text{HF}+\text{LF})] \times 100); index of modulation of the parasympathetic branch of the ANS as it influences the sinoatrial node of the heart</td>
</tr>
</tbody>
</table>

3.4.1.1.1 Data cleaning and processing

The RHRV package within the R program is an online, open source data analysis tool, which enables transparency in data computation and analysis (Rodríguez-Liñares et al., 2011; Vila, Lado, Mendez, Olivieri, & Linares, 2009). This method of analysis has not yet been reviewed systematically, but has been published in a peer-reviewed journal (Rodriguez-Liñares et al., 2011) and was a recommended software tool alongside two widely-used analysis systems, such as MATlab and Kubios (Physionet, 2009). Further, given the prospective, longitudinal nature of this study and the large sample of healthy youth athletes who participated in the baseline study (N=553), analysis software with flexibility in the script allowed for the time-efficient analysis of consecutive data files.

The following steps outline the data cleaning and processing of the HRV variables within the RHRV script (R Core Team, 2014).

1. RR intervals, or the time between successive R complexes is calculated using the RHRV package. However, these time series are not equidistantly sampled, due to the variability of heart rate.

2. The InterpolatedNIHR function (4Hz) within the RHRV program interpolates the variable RR intervals by creating an equidistant time series. This function allows for a
uniformly sampled heart rate series, which is essential for calculating frequency domain measures.

4. Since the recording of HRV is susceptible to noise within the heart rate signal, it is filtered using the FilterNIHR function. First, an algorithm uses an adaptive threshold for rejecting beats whose value exceeds the cumulative mean threshold. Second, standard values are obtained by identifying minimum and maximum heart beats per minute. The default values of the RHRV program, which were implemented for this protocol, were assigned as a minimum of 25 beats per minute and a maximum of 200 beats per minute. Time domain analysis is calculated via the CreateTimeAnalysis function within the RHRV program. Here, the RHRV program allows for the specification of the window (300 second window frames, 50% overlap) that will be used to calculate the RR intervals, which is set for the entire recording in this protocol.

5. The frequency analysis is created via the transformation of the signal using the Fast Fourier Transform method (FFT). Fast Fourier Transform is a non-parametric method for determining the power spectrum density of the HRV signal (Task Force, 1996).

6. The CalculatePowerBand function in RHRV is used to calculate the power spectrum density of the RR intervals using FFT. The window size (300 seconds) and window shift (300 seconds) are defined in the R script outlined in Appendix 7. Window size is the length of time that the HRV signal is captured for the frequency analysis, and window shift is the displacement of the window across the recording. In this protocol, consecutive windows are observed throughout each recording to determine the frequency domain parameters. The frequency ranges used in this protocol were set to the standards outlined by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Task Force, 1996).

7. Duration of the recording influences many HRV indices, thus recordings that were <14 hours and were not continuous recordings were excluded (Aubert et al., 2003). See Appendix 7 for the full script that was used within the RHRV package.
3.4.1.2 Statistical analysis

The statistical program, R: A Language and Environment for Statistical Computing (R Core Team, 2014), was used for all statistical analyses. The distribution of each HRV outcome variable was examined with a Cullen and Frey plot to assess skewness and kurtosis. Gamma distributions provided the best fit for distribution of HRV outcome variables and were modelled towards a Gamma family mixed model with a log-link function. Thus, generalized linear mixed models were employed to explore the effect of concussion on HRV, along the recovery trajectory, while considering post-concussion symptom domains and examining potential differences between concussed and control participants. Generalized linear mixed models are best suited to this study’s objectives as they allow for additional flexibility in modelling the distribution of the outcome directly (Cnaan, Laird, & Slasor, 1997). Here, a random intercept model was derived; intercepts are allowed to vary where the scores on the dependent variable for each individual observation are predicted by the intercept that varies across groups. This model assumes that slopes are fixed (the same across different contexts). Formal goodness of fit statistics were tested for each outcome variable with Akaike Information Criterion (AIC), in which lower values represent better fit. Modelling is an iterative approach with the goal of creating parsimonious models, in which variables are selected to remain in the model if they contribute to enhancing the fit of that model, or they are removed because they lower the fit and make no significant contribution.

The following considerations were taken into account and highlight the suitability of this statistical approach:

- Data for calculating HRV variables was missing in varying degrees (e.g., recordings excluded if they were <14 hours of a consecutive recording), and in the number of follow-up visits per participant. The variation in these factors are accounted for by employing a mixed modelling strategy, which allows for a different number of follow-up assessments per participant. For the concussed group (N=29), length of recording was $M = 19.45$ hours, $SD = 4.37$. Within the control group (N=15), length of recording was $M = 22.90$ hours, $SD = 3.26$. In terms of number of follow-up assessments, concussed group: $Mdn = 3$, $range = 1-9$; control: $Mdn = 3$, $range = 1-7$.
- To explore the relationship between PCSI domains (physical, cognitive, emotional and fatigue), the same linear mixed models were employed. However, due to sample size
limitations and concerns for multicollinearity, each domain was loaded into separate models.

- Sex, age, and history of concussion were accounted for in these models. However, inclusion of those covariates in the models resulted in higher AIC values (lower fit). Thus, they were omitted to satisfy parsimonious models.
- Baseline HRV variables were accounted for in the models as variation exists among healthy individuals (Paniccia et al., 2017, revisions in submission to *Frontiers in Neurology - Autonomic Neuroscience*), which may contribute to differing autonomic responses to concussive injury.

Taken together, the models generated for this study resulted in a random intercept model (with all main effects remaining fixed). Here, the uniqueness of each participant’s recovery trajectory is captured by utilizing participant ID as a random intercept, allowing each individual participant’s trend to vary along days post-injury. Applying a random intercept to participant ID is appropriate given the different variance structures across groups. The statistical threshold for significance was set to $p<0.05$.

### 3.5 Results

A total of 44 participants were included in the analysis (concussed= 29; control= 15). As this study was part of doctoral work, time resources were insufficient to collect the additional 14 participants required to balance the comparison groups (i.e., recruitment of controls was lengthy and challenging). Concussed participants and matched controls were similar on all HRV variables as well as PCSI values at baseline; that is, there were no statistically significant differences. As well, there were no significant sex differences at baseline on HRV variables, with the exception that females had lower HFnu compared to males. Descriptives for HRV values for concussed and control participants at baseline can be found in Table 3.2. In terms of PCSI baseline values, females reported significantly more physical symptoms, males reported significantly more fatigue symptoms, and females reported more overall symptoms compared to males. Some effects of age on baseline PCSI were also found; for every increase in age by one year, physical symptom score increased by 0.37 and cognitive symptom score increased by 0.34.
Table 3.2 Descriptive HRV values for concussed and control participants at baseline

<table>
<thead>
<tr>
<th></th>
<th>Baseline HRV Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>SDNN</td>
<td></td>
</tr>
<tr>
<td>Concussed</td>
<td>206.61 (62.04)</td>
</tr>
<tr>
<td>Control</td>
<td>194.05 (55.00)</td>
</tr>
<tr>
<td>RMSSD</td>
<td></td>
</tr>
<tr>
<td>Concussed</td>
<td>74.48 (30.94)</td>
</tr>
<tr>
<td>Control</td>
<td>78.63 (31.95)</td>
</tr>
<tr>
<td>pNN50</td>
<td></td>
</tr>
<tr>
<td>Concussed</td>
<td>27.51 (10.63)</td>
</tr>
<tr>
<td>Control</td>
<td>31.12 (12.88)</td>
</tr>
<tr>
<td>HF</td>
<td></td>
</tr>
<tr>
<td>Concussed</td>
<td>556.77 (373.28)</td>
</tr>
<tr>
<td>Control</td>
<td>560.23 (352.01)</td>
</tr>
<tr>
<td>HFnu</td>
<td></td>
</tr>
<tr>
<td>Concussed</td>
<td>36.91 (9.60)</td>
</tr>
<tr>
<td>Control</td>
<td>41.53 (9.10)</td>
</tr>
<tr>
<td>Mean HR</td>
<td></td>
</tr>
<tr>
<td>Concussed</td>
<td>77.01 (4.38)</td>
</tr>
<tr>
<td>Control</td>
<td>75.99 (9.28)</td>
</tr>
</tbody>
</table>

In the concussion analyses, age, sex and concussion history factors were accounted for, however, these variables were not significant nor made contributions of increased fit in the analyses and thus were dropped from the models and not reported below. Concussed participants were primarily competitive/representative level athletes (N=22 [75.9%], followed by house league N=2 [6.9%], recreational N=2 [6.9%], [N=1 missing]). Primary sport: hockey N=17 (58.6%), soccer N=5 (17.2%), other N=6 (20.6%, cross-country, skiing, rugby). Regarding the seasonality of their injury, nearly half of the concussed participants sustained their concussion in September (N=7), February (N=4), and November (N=4); no concussions were sustained over the summer months of June, July or August. Control participants were also primarily representative level athletes (N=8 (53.3%), followed by house league N=3 (20%), recreational N=1 (6.6%), [N=2 missing]). Primary sport: hockey N=4, soccer N=4, other N=4 (baseball, track and field), [N=2 missing]). Participant demographic information and injury characteristics can be found in Table 3.3.

SDNN. No significant differences in SDNN were found when considering days post-injury, post-concussion symptom domains (physical, cognitive, emotional and fatigue), symptom status
(symptomatic/asymptomatic), and concussed participants were not significantly different from controls. These results were present after controlling for a significant baseline SDNN value ($B = 0.160, p < 0.001$), whereby a participant’s healthy baseline value was positively associated with their post-injury value. See Table 3.4 for model statistics.

**RMSSD.** Mixed modelling revealed a main effect of days post-injury ($B = 0.0001, p = 0.02$), whereby a positive association was found between RMSSD and days post-injury; that is, RMSSD increased as days post-injury increased. When examining the visual trajectory of this finding (Figure 3.1), a decrease appeared to occur 15 days post-injury and decreased until day 30, followed by levelling off at approximately 50 days. Post-concussion symptom domains (physical, cognitive, emotional and fatigue), and symptom status (symptomatic/asymptomatic) were not significant injury variables in this model. Concussed participants were not significantly different from controls. These results were present after controlling for a significant baseline value ($B = 0.186, p < 0.001$), whereby a participant’s healthy RMSSD baseline value was positively associated with their post-injury value (Table 3.4).
Table 3.3 Participant and injury characteristics

<table>
<thead>
<tr>
<th>Demographic Information</th>
<th>Concussed (N=29)</th>
<th>Control (N=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) Mean (SD)</td>
<td>15 (1.48)</td>
<td>15 (1.66)</td>
</tr>
<tr>
<td>Sex</td>
<td>21 females/8 males</td>
<td>11 females/4 males</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>History of Concussion N (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No history</td>
<td>16 (55.2%)</td>
</tr>
<tr>
<td>One</td>
<td>7 (24.1%)</td>
</tr>
<tr>
<td>Two</td>
<td>3 (10.3%)</td>
</tr>
<tr>
<td>&gt; Three</td>
<td>2 (6.9%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Baseline PSCI Total Median (range)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>0 (0-7)</td>
</tr>
<tr>
<td>Cognitive</td>
<td>0 (0-5)</td>
</tr>
<tr>
<td>Emotional</td>
<td>0 (0-5)</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0 (0-4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Days from Baseline to Concussion Median (range)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>93 (3-325) days</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACE Form Injury Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Blow to head (yes)</td>
<td>16 (55.2%)</td>
</tr>
<tr>
<td>Cause (Sport)</td>
<td>26 (89.6%)</td>
</tr>
<tr>
<td>Retrograde Amnesia (yes)</td>
<td>2 (6.9%)</td>
</tr>
<tr>
<td>Range of time</td>
<td>&lt;5 seconds</td>
</tr>
<tr>
<td>Anterograde Amnesia (yes)</td>
<td>1 (3.4%)</td>
</tr>
<tr>
<td>Range of time</td>
<td>1-2 minutes</td>
</tr>
<tr>
<td>Loss of consciousness (yes)</td>
<td>1 (3.4%)</td>
</tr>
<tr>
<td>Range of time</td>
<td>5-10 seconds</td>
</tr>
<tr>
<td>Headache history</td>
<td>1 (3.4%)</td>
</tr>
<tr>
<td>Migraine history</td>
<td>1 (3.4%)</td>
</tr>
<tr>
<td>Psychiatric history</td>
<td>2 (6.9%)</td>
</tr>
<tr>
<td>Range of post-concussion follow-up visits</td>
<td>1-9</td>
</tr>
</tbody>
</table>
**pNN50.** Mixed modelling revealed a main effect of days post-injury ($B = 0.0009, p = 0.029$), whereby with increasing days post injury, pNN50 increased. Here, the visual trajectory of this finding reflected an immediate decrease from day of injury, decreasing until 30 days post injury. PNN50 values then increase until day 65, followed by a plateau (Figure 3.2). Significant main effects of post-concussion symptom domains were also found. A positive, significant relationship was found between the physical domain and pNN50, whereby concussed participants who reported more physical symptoms were found to have increased pNN50 ($B = 0.016, p = 0.019$). The same trend was found for the cognitive domain, whereby increased reports of cognitive symptoms were associated with increased pNN50 ($B = 0.023, p = 0.012$). As well, increased reports of fatigue domain symptoms was also significantly related to increased pNN50 ($B = 0.028, p = 0.030$). These results were present above and beyond the significant effect of baseline pNN50, controlled for in these models ($B = 0.196, p = 0.0002$; higher baseline pNN50 was positively associated with higher post-injury pNN50). There were no significant effects of the emotional symptom domain and symptom status (symptomatic/asymptomatic). Concussed participants did not have significantly different pNN50 compared to controls (Table 3.4).

**HF.** Mixed modelling revealed a main effect of days post-injury ($B = 0.001, p = 0.005$), whereby concussed participants were found to have increasing values of HF as days post-injury increased. When examining the visual trajectory, there is generally a decrease starting at day 10 post-concussion, with continued decrease until day 30, followed by increases until day 50 and plateauing thereafter (Figure 3.3). All four post-concussion symptom domains were also found to have a positive and significant main effect on HF. With increased report of physical symptoms, significant increases in HF were found ($B = 0.064, p < 0.001$). For concussed participants who reported more cognitive symptoms, increases in HF were found ($B = 0.138, p < 0.001$). Similarly, a positive relationship between emotional symptoms and HF was found ($B = 0.305, p < 0.001$). Finally, in concussed participants who reported more fatigue domain symptoms, increases in HF was also found ($B = 0.131, p < 0.001$). A main effect of concussion status was also found, in which concussed participants were found to have significantly higher HF compared to controls ($B = 0.101, p < 0.001$). Within the concussed participants, symptomatic versus asymptomatic participants did not significantly differ in their values of HF. These findings were present after controlling for baseline HF, which was not significant in this model (Table 3.4).
Figure 3.1 Relationship between RMSSD, concussion symptom domain and days post concussion where day 0 marks the day of first follow-up. The red and grey trend line represents the lowess smooth line, which maps an average trajectory for all concussed individuals.
Figure 3.2 Relationship between pNN50, concussion symptom domain and days post concussion where day 0 marks the day of first follow-up. The red and grey trend line represents the lowess smooth line, which maps an average trajectory for all concussed individuals.
Figure 3.3 Relationship between HF, concussion symptom domain and days post concussion where day 0 marks the day of first follow-up. The red and grey trend line represents the lowess smooth line, which maps an average trajectory for all concussed individuals.

**HFnu.** Mixed modelling revealed a main effect of days post-injury ($B = 0.0008$, $p < 0.001$), whereby concussed participants were found to have increasing values of HFnu as days post-injury increased. All four post-concussion symptom domains were also found to have a positive and significant main effect on HFnu. With increased report of physical symptoms, significant increases in HFnu were found ($B = 0.014$, $p < 0.001$). For concussed participants who reported more cognitive symptoms, increased HFnu was found ($B = 0.033$, $p < 0.001$). Similarly, there was a positive relationship between emotional symptoms and HFnu ($B = 0.069$, $p < 0.001$). Finally, for concussed participants who reported more fatigue symptoms, increases in HFnu was found ($B = 0.022$, $p < 0.001$). Within the concussed participants, symptomatic versus asymptomatic
participants did not significantly differ in their values of HFnu. These findings were present after controlling for baseline HF, which was not significant in this model (Table 3.4).

Across all HRV variables, sex was not found to be a significant predictor of differential recovery trajectories following concussion. However, recovery trajectories stratified by sex are presented in Appendix 9.

**Table 3.4 Mixed effect model estimates**

<table>
<thead>
<tr>
<th>Trajectory of Time</th>
<th>Estimate (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SDNN</td>
</tr>
<tr>
<td>Baseline value</td>
<td>0.160 (&lt;0.001)*</td>
</tr>
<tr>
<td>Days post injury</td>
<td>-0.0001 (0.712)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effect of Symptom Domains in Concussed Individuals</th>
<th>Estimate (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCSI - Physical</td>
<td>NS</td>
</tr>
<tr>
<td>PCSI - Cognitive</td>
<td>NS</td>
</tr>
<tr>
<td>PCSI - Emotional</td>
<td>NS</td>
</tr>
<tr>
<td>PCSI - Fatigue</td>
<td>NS</td>
</tr>
<tr>
<td>Symptom Status (symptomatic versus asymptomatic)</td>
<td>NS</td>
</tr>
</tbody>
</table>

**Note:** “*” denotes a significant main effect where p<0.05. “NS” denotes a non-significant effect.

### 3.6 Discussion

It has been become increasingly clear that a purely symptomatic or pathophysiologic approach to understanding the concussion recovery trajectory has shortcomings. While the majority of youth recover from concussion and return to activity within 4 weeks (McCrorry et al., 2017; Zemek et al., 2016), there is a dearth of research that corroborates clinical recovery alongside potential physiological changes. This study is one of the first studies that aimed to bridge both of these approaches, in a youth athlete population following concussion. In addition, a recent systematic review on post-concussion cardiac autonomic function highlighted the need for more substantial repeated measures follow-up and a focus on pediatric populations (Blake et al., 2016). The novelty in this study is the multiple follow-up assessments where both subjective concussion
symptoms and HRV were collected. Findings suggest a general trend of increasing HRV along the recovery trajectory. The relationship between concussion symptoms and HRV revealed differential trends along days post-injury, which reflects a non-linear and dynamic physiological pattern in concussion recovery.

3.6.1 HRV along days post-injury

This study found a general increase over days post-injury in concussed youth athletes across all HRV variables except SDNN. However, in the initial 30-40 days of concussion, HRV is shown to decrease. Among the various HRV measures, decreases of 14-25% were observed in this time period. Following this period, the trend then proceeds to increase until approximately day 75 (8-26% increase across HRV measures), and plateaus thereafter. This trend should be interpreted with caution, as there are fewer data as days post injury increases. Nonetheless, this trend is consistent across HRV measures and provides a foundation to further investigate the trajectory of physiological measures in youth concussion. These findings are somewhat in contrast to a prospective cohort study of varsity athletes, which revealed significant differences in the acute phase of concussion (days 1-7), but these were only found in RMSSD compared to other HRV measures (Berkoff, Boggess, Bytoniski, & Stafford, 2008). It is important to note that looking at HRV during an isolated period of time (acute injury) may depict changes in HRV as linear; that is, an expectation that HRV may be linearly decreasing or increasing. The strength of this repeated measures study is in the visualization where the trajectory of time revealed trends of decreasing HRV, followed by trends of increasing HRV. The mechanism underlying this differential autonomic modulation is still unknown. However it is hypothesized that an “uncoupling” exists between the ANS and cardiovascular systems. In essence, the communication between these two systems has been perturbed enough to release the tonic inhibition of the sympathetic nervous system or reduce parasympathetic nervous activity, driving the heart to exhibit less variability (Goldstein et al., 1998); the mechanism responsible for the uncoupling is still unknown and may represent dysregulated shifts between the parasympathetic and sympathetic branches of the ANS, especially during exertion (Hinds, Leddy, Freitas, & Willer, 2016). Levine et al. (2008) state that changes in autonomic function may be ascribed to subtle alterations in diffuse brain volume loss. Similarly, axonal shearing in various pathways and brain regions may also contribute to autonomic cardiovascular modulation (Huang et al., 2009; Niogi et al., 2008).
3.6.2 HRV and post-concussion symptom domains

When examining post-concussion symptom domains as a main effect, a consistent result was found across some of the HRV measures (pNN50, HF, HFnu), whereby a positive relationship between increased symptom reporting (across physical, cognitive, emotional and fatigue) and increased HRV was found. Here, those who reported more concussion symptoms displayed increased HRV and those who reported fewer concussion symptoms had lower HRV. This finding differs significantly from research to date. Following concussion, it is not uncommon to receive reports of symptom exacerbation following physical and cognitive exercise and cardiac autonomic function may be mediating this relationship; in a concussed adult sample, physiological markers of increased sympathetic output have been found (e.g., decreased HRV; Ellis et al., 2015, 2016; Leddy et al., 2017). As well, increases in symptom reporting or psychological stress have been associated with decreased HRV (Hutchison et al., 2017; Paniccia et al., 2017; Senthinathan et al., 2017). It is worth noting that these cited studies were conducted in more controlled and short-term data collection environments (e.g., assessing change in HRV following positional changes); thus, their direct comparison to this study warrants caution. These methodological differences are further discussed in the limitations section. Nonetheless, potential hypotheses for this opposite trend include (1) the role of consistent clinical education follow-ups within this study and (2) the motivation of youth athletes. Regarding the role of clinical follow-up, all concussed participants received one-on-one concussion education on management strategies regarding graduated return to activity and symptom limited activity (cognitive and physical; see procedure). It may be possible that this served as a clinically meaningful interaction for the concussed youth athletes. For example, those with increased symptoms may have followed the management strategy to rest and graduate their level of activity. This in turn, may have served as modulatory feedback to the ANS and influenced homeostasis (increased HRV; Leddy, Kozlowski, Fung, Pendergast, & Willer, 2007). Davis et al. (2017) also indicated that students who receive follow-up are more likely to receive accommodations, facilitating recovery. By contrast, the finding that concussed youth athletes with fewer symptom reports had lower HRV may be partially explained by the fact that high-level athletic performance serves as strong motivation to minimize or deny symptoms (Bailey et al., 2006; Echemendia et al., 2001). According to the follow-up education provided as part of the study protocol, youth athletes would have received information on trialing pre-injury activities if they reported feeling better or had a resolution of symptoms. The implication of this novel finding is that changes in HRV may
have the potential to be altered based on environmental influences such as support or consistent clinical education. While this was not the intent of the study protocol, it behooves the concussion community to further investigate external factors, which may alter the recovery trajectory for youth athletes.

3.6.3 HRV and injury status

The clinical neuroscience of concussion is continuously evolving because the complexity of concussion is seen in its idiosyncratic and diffuse pathology presentation throughout the brain (Bigler, 2008). These characteristics contribute to the challenge in detecting change within cardiophysiological parameters (Keren et al., 2005). In this study, no differences were found across all HRV measures when comparing concussed youth athletes to controls (with the exception of HF). In adult athletes samples of concussion, findings have been mixed in illustrating a difference between concussed and control participants. A prospective cohort of junior hockey players revealed that concussed individuals had significantly lower HF compared to controls at 5 and 10 days post injury during low-to-moderate exercise (Gall et al., 2004). Similarly, La Fountaine et al. (2011) revealed changes in HR complexity during isometric hand-grip exercise, that were altered within 48 hours of head injury, resolved within 1 week and returned to control levels 2 weeks later. More recently, Hutchison et al. (2017), found that controls had higher HF compared to concussed university athletes across symptomatic, asymptomatic and return-to-play time points; however other HRV measures did not show the same change across time. Abaji et al. (2016) also demonstrated that asymptomatic athletes in the post-acute stage of concussion presented with reductions in HRV, compared to non-concussed athletes, during the isometric hand grip test. In the current study, changes in HRV also did not differ between those who were symptomatic versus those who were asymptomatic. This may indicate that physiological reactions occur above and beyond the clinical resolution of symptoms (as seen in the data visualizations along days post-injury), which may have implications for the clinical determination of return-to-activity (Prichep, McCrea, Barr, Powell, & Chabot, 2013; Shrey, Griesbach, & Giza, 2011). Here again, these comparisons warrant caution as this study employed a 24-hour recording, versus controlling data collection within the context of a specific task. Comparable to this study’s findings, La Fountaine et al. (2009) found no significant differences in HRV at rest or during an isometric handgrip test 48 hours or 2 hours following concussion. Similarly Su et al. (2005) found no significant differences in HRV measures (LF,
HF, LF:HF) when comparing concussed versus control participants, ranging in age from 13-78 years old. It is worth noting that the measurement protocols of evaluating HRV in resting or exercise-induced states vary across studies. The present study did not induce stress in the form of exercise or strength tests, which might be a key factor in detecting differences.

Taken together, there appears to be large within-group variability in examining HRV following concussion. It has been postulated that autonomic dysregulation may present as a sub-clinical phenomena for those who have sustained a concussion (Hilz et al., 2011) and a physiological threshold may exist for those differences to be detectable (Biswas et al., 2000). In a study examining changes of HRV across severe, moderate and mild TBI, HRV differences were only found with moderate and severe TBI, while mild TBI values were similar to controls (Hilz et al., 2011). Relating back to this study’s findings, it is still unclear if the findings observed represent a typical response to a stressful event (having a concussion) or if autonomic dysregulation is occurring above and beyond this response. It may be possible that the actual injury isn’t reflected in physiological changes but rather the reaction of stress to the injury that provides vital information on physiological recovery. Changes in HRV have been found to reflect both physiological and psychological stress levels after concussion (Hutchison et al., 2017). Given that concussion presents as a functional versus structural injury, it may be possible that concussion is experienced as a form of stress, with the ANS reacting in a way that is in line with normal function. Deciphering if the primary concussion injury or the secondary psychological response/stress associated with the concussion drives these changes is challenging. The smaller sample of controls limits the ability to make conclusions. Nonetheless, the widespread finding of no difference between concussed and control participants may be reflective of the secondary response, which may be less detectable between groups.

3.6.4 Demographic factors

Age and sex differences were not present in this study, however, the current study’s sample was predominantly female. Thus, the skewed sample may have contributed to the inability to detect sex differences. In university athletes, however, concussed females have been shown to have greater suppression of HRV compared to males (Hutchison et al., 2017). History of concussion also did not appear to play a role in the findings. Again, however, other studies have demonstrated lower HF in concussed athletes with a previous history compared to controls.
(Abaji et al., 2016; Senthinathan et al., 2017). This study’s sample had a concussion history of 41.3% and 46.7% for concussed and control participants, respectively. Given the sample size, it is unknown if there are indeed chronic effects of concussion. Based on the modeling approach used in this study, it is also important to appreciate that when multivariable analyses are conducted (as found in previous concussion literature; Miller et al., 2016; Zemek et al., 2016), significant univariate findings drop out. Based on this study, it may be that concussion results in a temporary disruption in autonomic control of cardiovascular function. With a larger sample size and adequate control, these potential demographic differences may be elucidated in future studies.

### 3.7 Limitations

While this study is one of the first study’s to examine the physiological recovery trajectory for concussed youth athletes, it is not without limitations. It was not feasible within the context of a large pre-injury baseline study to collect other meaningful variables such as physical activity repertoires. The physical activity levels of concussed and control participants were likely different due to concussed participants’ inability to engage in physical activity. This is important to consider as changes in exercise training have been shown to significantly alter vagal tone (increase HRV over time; Aubert et al., 2003; Gutin et al., 2005). Given the 24-hour recording protocol, physical activity repertoires (frequency, duration and intensity) of activity across the various follow-up time points will be important to consider for future study and likely will contribute valuable information to assist in the interpretation of change in HRV.

According to the most recent consensus statement, a single “physiological time window” for concussion recovery does not exist due to methodological differences in assessing physiological measures and study design (McCrory et al., 2017). Multiple studies have suggested physiological dysfunction that outlasts clinical measures of recovery (Ellis et al., 2016; Hutchison et al., 2017; Leddy et al., 2017), but this has not been conclusively established. The challenge present in this study was the inability to directly compare results to other similar concussion studies given the difference in recording protocol. This study employed a non-controlled, 24-hour recording protocol in which participants were able to go about their daily lives. This is in contrast to the majority of HRV concussion studies, which employ resting state position protocols or observe change in HRV according to exercise exertion. While this 24 hour protocol introduces variability
and noise within the HRV signal, the ability of trends to be seen despite this, is indicative of a potentially salient signal, and one that may be more ecologically valid (Eckberg, 1980; Kleiger et al., 2005) when gauging the physiological response to concussive injury. However, regarding the baseline values, normative studies in adolescents examining 24-hour recordings show similarity across the measures collected in this study. For example, Faulkner, Hathaway, & Tolley (2003) examined healthy adolescents (15 years old +/- 1.6) and reported similar baseline values and ranges on pNN50, RMSSD, SDNN. Similarly, another study examined normative ranges in children and youth ages 3-18 years old; here, the same overlap with this study’s values was not consistent and may be due to the larger age range employed in the referenced study (Bobkowski et al., 2017). Nonetheless, the finding that baseline values between concussed and control groups were similar and that baseline values compare to analogous studies may indicate promise in using 24 hour recording as an ecologically valid methodology to observe change in the ANS. This assessment protocol may be the initial first step in using a dynamic protocol over a sufficient length of time to gauge how the ANS fluctuates in response to concussion over time.

Although concussion research has supported the organic, pathophysiological manifestation of symptoms, emerging trends in examining recovery trajectories are also exploring the role of affective/emotional, personality and stress responses as mediators of recovery (Hanna-Pladdy, Berry, Bennett, Phillips, & Gouvier, 2001; Iverson et al., 2017). For example, according to the coping hypothesis, the fatigue and stress involved in dealing with environmental demands (return to school, return to sport) may exacerbate certain symptoms, in a way that is secondary to the concussion (Long & Novack, 1986). Here, common difficulties arise in establishing active problem solving, having a more depressive attitude towards coping, and persisting difficulties with cognitive function (Bohnen & Jolles, 1992). It is possible that increased perceived stress and the resulting symptoms, impair the youths’ ability to adapt to their pre-injury life. There is value in exploring the appropriateness of the control group, where most research has included a “healthy” control. Concussion symptoms are subjective and non-specific in nature (Hunt et al., 2016) and they are experienced variably based on daily stressors within a healthy populations (Kristman et al., 2014). It is possible that the experience of a concussion changes the threshold with which a youth athlete subjectively reports symptoms. For example, a youth may report a high level of baseline symptoms and after sustaining a concussion, realize that the way they rated themselves at baseline was an inflated report of daily symptoms and re-adjust their threshold.
Thus, it may be clinically relevant to observe the differences between a symptomatic concussed group and a symptomatic healthy group to observe if the physiological signals seen across time are directly related to the concussive injury or a maladaptive coping style in response to somatic symptoms. It is important to consider that concussion is experienced variably; with no biological marker in place or conclusive neuroimaging techniques for diagnosis (McCrory et al., 2017). Thus, this variability may also be reflected in the physiological phenomenon explored in this study whereby the degree of autonomic derangement may also vary with the individual (Oppenheimer, 2006). Future research in exploring the effect of daily stress factors on the recovery trajectory in this population is warranted.

Finally, this study was mainly composed of concussed female athletes. Sex differences were accounted for in the models (yet not significant), however, this finding may have been due to the skewness in sex distribution. When considering the relationship between concussion-like symptoms and HRV in healthy youth athletes, one study revealed significant differences whereby females displayed lower HRV compared to males (Paniccia, et al., 2017). Nonetheless, given that research indicates that females experience more concussions than males (Zemek et al., 2016), it is not surprising that this prospective study yielded that same trend.

### 3.8 Conclusion

Understanding the trajectory of recovery following a concussion has been challenging because their lacks a gold standard, in addition to the reliance on subjective symptom reporting (McCrory et al., 2017). This study explored the effect of concussion on HRV along days post-injury, when considering subjective clinical measures (concussion symptom domains). Findings indicate a varied trajectory of HRV, with declines experienced up until approximately day 40-50, followed by an overall expected increase in HRV thereafter and plateauing. These physiological findings did not manifest as expected with concussion symptom domains (e.g., increased HRV found with increased reports of symptoms in physical, cognitive, fatigue and emotional domains). While these findings may have been influenced by the presence of clinically-informed education follow-ups along the recovery trajectory, the application of these findings are in an early stage before they can be integrated into assessment protocols. However, the results appear to illustrate the positive feedback that clinical education has on ANS function following concussion and the potential to alter the expected course of physiology along the recovery trajectory. Finally, this
study does act as a first step in looking at the natural history of concussion, while accounting for significant pre-injury HRV and the follow-up of youth athletes across multiple time points. Future research exploring the role of perceived stress and personal athlete characteristics will be valuable to decipher if concussion impacts the ANS above and beyond what would be expected from a stressful life event.
3.9 References


Chapter 4
Mindfulness-based Yoga for Youth with Persistent Concussion: A Pilot Study

4 Overview

This chapter presents a pilot feasibility study on the impact of mindfulness-based yoga on youth with persistent concussion symptoms. Here, physiological and functional outcomes are linked in an effort to explore change in HRV from a clinically relevant perspective, while focusing on youth-centred outcomes such as self-efficacy, participation and physical activity repertoires. This chapter presents pilot data which encompasses the spectrum of factors within the BPS model; physiological mechanisms in the form of HRV during each intervention session and outside of the intervention session, psychosocial factors such as changes in participation in meaningful occupation, and health outcomes such as self-efficacy and post-concussion symptoms following a clinical intervention.

An abbreviated form of this chapter has been accepted and is currently in press with the American Journal of Occupational Therapy. This journal provides a forum for the dissemination of research examining the effectiveness and efficiency of occupational therapy practice and welcomes a broadened scope, which includes physiological outcomes.

Paniccia, M., Knafo, R., Thomas, S., Taha, T., Ladha, A., Thompson, L., & Reed, N.

4.1 Abstract

Background: Approximately 20-30% of youth who have sustained a concussion experience symptoms beyond one month, with some experiencing challenges in the months and years following the injury. Limited interventions address persistent symptoms in a way that can enhance participation and self-efficacy. Mindfulness-based yoga (MBY) is a mind and body intervention that focuses on engaging in the present moment with a purposeful attention on breath and awareness of thoughts. Heart rate variability (HRV) is emerging in concussion research as a neurophysiological measure that captures an individual’s ability to be flexible and adaptable in their environment. Examining HRV in
the context of MBY can provide insight into a youth’s ability to self-regulate in the context of persistent concussion symptoms. The objectives of this study are to: (1) investigate the impact of MBY on participation and self-efficacy in youth with persistent concussion symptoms; (2) explore the links between physiological measures (HRV) and subjective (participation and self-efficacy) measures of function. **Method:** Case series design. Youth ages 13-17 years old (N=6) with concussion symptoms greater than one month, participated in an 8-week MBY intervention, 1x/week, for 45 minutes. Participation, self-efficacy and HRV (collected over 24 hours) were collected pre-, post-, and three months following MBY. Secondary measures such as post-concussion symptoms and physical activity repertoires were collected along the same aforementioned timeline. HRV was also collected during each MBY session. **Results:** Trends towards increasing self-efficacy in academic, social and emotional domains were found following MBY and maintained at the 3-month follow-up. Trends of increasing HRV were also found pre-post intervention and within the eight MBY sessions. Finally, trends of decreasing post-concussion symptoms across physical, cognitive, fatigue and emotional domains were found following MBY and maintained at the 3-month follow-up. **Conclusion:** Preliminary results reveal positive trends of a novel, safe intervention for youth with persistent concussion symptoms and the value of exploring both occupation-based and physiological measures. Future research with a larger sample and control group is warranted.

### 4.2 Introduction

Concussion is a pathophysiological injury induced by biomechanical forces, which can be caused by impact to the head, neck or body (McCrorry et al., 2013). Approximately 30% of youth who have sustained a concussion do not recover in the average timespan of one month, and continue to experience prolonged symptoms (Zemek et al., 2016). These symptoms include a constellation of physical (e.g. headaches, nausea), cognitive (e.g. trouble remembering or mental fog), emotional symptoms (e.g. irritable, anxious) and fatigue issues (e.g. trouble falling and staying asleep). Defined by the International Statistical Classification of Disease and Related Health Problems (ICD-10), persistent concussion syndrome (herein referred to persistent concussion symptoms) is defined as symptoms that persist beyond one month (Steindel, 2010). This pilot study aims to assess the impact of mindfulness-based yoga (MBY) on youth with persistent concussion symptoms and further, to observe potential changes in both functional and physiological measures.
4.2.1 Persistent concussion in youth

In Canada, 53.4% of head injuries in emergency departments were accounted for by children 10 to 14 years old, and 42.9% accounted for youth 15 to 19 years old (Kelly, Lissel, Rowe, Vincenten, & Voaklander, 2001). Specific to Ontario, concussions represented 21% of head injuries in students; these students were two times more likely to report very high emotional distress and have less successful academic outcomes (Ministry of Education, 2014). Here, it is evident that persistent concussion necessitates specialized concussion management beyond return-to-activity guidelines (McCrory et al., 2013). The landscape of concussion treatment, in Canada specifically, has been summarized: (1) to lack consistency in the training and knowledge on traumatic brain injury, (2) to recommend unnecessary costly and unsubstantiated treatment, and (3) were not in line with evidence-informed guidelines (Ellis et al., 2017). Within the scarce public sector services available, management of persistent concussion is often constrained by limited appointments and a “consultative” approach. This approach is still, significantly costly, ranging from $1000 to $2000 per youth in a public rehabilitation hospital setting (Jason Carmichael [Co-director of the Concussion Centre, Holland Bloorview Kids Rehabilitation Hospital], person communication, March 24, 2017). There is a clear gap in the current service delivery model and the needs of this population to return to meaningful activity. This pilot study aims to assess the feasibility of a clinically informed, group-based intervention for youth experiencing persistent concussion symptoms.

4.2.2 Current clinical recommendations

Activity restrictions in the form of physical and cognitive rest have typically been prescribed as part of evidence-informed guidelines for youth who are experiencing concussion symptoms (McCrory et al., 2013). While this recommendation may be valuable in the acute phase (7-10 days), prolonged inactivity in the persistent phase (>1 month) may contribute to secondary psychosocial challenges (Paniccia & Reed, 2017; Reed et al., 2015). A significant shift in clinical recommendations has occurred whereby prolonged rest and inactivity are discouraged and symptom-limited activity is encouraged to promote recovery (Gagnon, Galli, Friedman, Grilli, & Iverson, 2009; Grool et al., 2016; Imhoff, Fait, Carrier-Toutant, & Boulard, 2016; Reed et al., 2015). These psychosocial challenges include reduced meaningful interactions with friends, teammates, teachers and coaches (Bloom, 2004; Broshek, De Marco, & Freeman, 2015; Jonsson
& Andersson, 2013). In recent studies, youth reported high levels of boredom, isolation and loss of activity paralleling their symptom reports of headaches and trouble concentrating (Iadevaia, Roiger, & Zwart, 2015; Stein et al., 2016). Youth have also expressed the emotional toll of not being able to engage in meaningful occupations such as school activities and sport in addition to “losing control” of their abilities (Iadevaia et al., 2015). Ultimately, youth with persistent concussion experience limited occupational repertoires; they don’t engage in the same number of occupations as previously, have difficulty participating, or avoid re-integrating out of fear of symptom exacerbation (Paniccia & Reed, 2017). In turn, these challenges impact self-efficacy, an individual’s perceived confidence in their abilities (Jonsson & Andersson, 2013). These findings underscore the importance of shifting from symptom-focused recovery to examining occupation-based factors such as self-efficacy and participation in meaningful activities, in the context of enabling continued recovery in youth with persistent concussion symptoms.

4.2.3 Persistent concussion and HRV

Persistent concussion is also being recognized as a neurophysiological phenomenon, whereby autoregulatory mechanisms (e.g. stress responses) of the brain do not achieve pre-injury levels of homeostasis (Ellis, Leddy, & Willer, 2016; Hutchison et al., 2016; Leddy, Kozlowski, Fung, Pendergast, & Willer, 2007). Heart rate variability (HRV) is an objective, neurophysiological indicator of autonomic nervous system (ANS) functioning (Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology [Task Force], 1996). HRV is quantified by measuring variation of the time intervals between heartbeats. The balance between the sympathetic and parasympathetic branches of the ANS reflect homeostasis, whereby an individual can adapt and respond flexibly to environmental demands. Increased variability in heart rate (i.e., increased HRV) is demonstrative of healthy neurophysiological function whereas decreased HRV may be reflective of challenges adapting and being flexible to the environment. Following the acute phase of concussive injury, collegiate athletes have demonstrated reduced HRV (homeostatic disturbance) despite symptom resolution (Abaji, Curnier, Moore, & Ellemberg, 2016). In other studies of young adult athletes, those with persistent concussion symptoms have also shown reduced HRV compared to controls and authors have suggested a delayed return to homeostasis following injury (Conder & Conder, 2014; Ellis et al., 2016; Leddy et al., 2007). Taken together, the experience of persistent
concussion symptoms may be related to the continued recovery of homeostasis. Investigating HRV in the chronic phase of this injury, in addition to functional measures, could provide a holistic understanding on persistent concussion symptoms in youth.

4.2.4 A novel approach to clinical intervention

Management of persistent concussion symptoms in youth can benefit from an approach that promotes safe levels of physical and cognitive activity during recovery, while also addressing the emotional toll of symptoms, including the rumination and distressing thoughts about functional performance. Common forms of yoga in Western practice have been rooted in Hatha yoga and meditation. Hatha yoga is mainly comprised of: (1) physical postures to lubricate joints, muscles and ligaments and (2) breathing techniques of inhalation, breath retention and exhalation (Collins, 1998). The type of yoga being proposed in the current study is mindfulness-based yoga (MBY). MBY differs from Hatha yoga in that individuals are welcomed to scan their bodies and become more familiar of the sensations they feel in varying physical postures (Kabat-Zinn, 2006). The mindful component, of present-focused sensory awareness, fosters focus and explicit awareness of the body, without active judgement. Rather, the individual is encouraged to come back to the breathe and center themselves in the present moment (Kabat-Zinn, 2006). MBY encourages participants to develop moment-to-moment awareness of physical sensations, emotions, and thoughts, and promotes the cultivation of non-judgemental and accepting relationships to personal experiences. Here, the link between the mind (emotional well-being) and body (physical activity) is key to consider given the lack of occupational repertoire that youth with persistent concussion symptoms experience. Past research using MBY interventions have demonstrated benefits in physical and psychological functioning (i.e., decreased stress, increased self-efficacy; Raghuram, Deshpande, & Nagendra, 2009). A pilot study by Azulay and et al. (2013) examined the effects of mindfulness-based stressed reduction in adults with persistent concussion symptoms. Increased quality of life and perceived self-efficacy with a moderate effect size was found, demonstrating a potential for applying this intervention to a broader population. MBY has the potential to shift the focus away from symptoms, while building self-efficacy and enhancing participation in daily activities.

The potential links between self-efficacy (in academic, social and emotional domains of daily life), participation and HRV are important to consider. HRV can capture an individual’s reaction
to external or internal stressors (Thayer & Lane, 2000), which in turn may relate to perceived self-efficacy to perform activities and influence level of participation. Linking these multidirectional measures can enhance our understanding of the occupation-based domains mentioned above, in addition to evaluating neurophysiological homeostasis. The primary objective of this study was to explore the potential impact of MBY in youth with persistent concussion symptoms on occupation-based (self-efficacy and participation) and physiological measures (HRV) across pre-, post- and 3-months following MBY. The secondary objective was to examine trends of post-concussion symptoms following MBY.

4.3 Methods

4.3.1 Design

Research Ethics Board approval and informed consent were obtained prior to data collection (see Appendix 10 for consent form). This pilot study utilized a case series, repeated measures design. Occupation-based (self-efficacy, participation), post-concussion symptoms, as well as physiological (HRV) measures were collected pre-, post- and 3 months following the MBY intervention. HRV was also collected during the MBY intervention.

4.3.2 Participants

Participants were recruited from hospital and community-based outpatient settings. Participants were included in the study if they were between the ages of 13-18 years old, English speaking and experiencing post-concussion symptoms for greater than four weeks. Exclusion criteria were the following: neurological disease; diagnosed cardiac issues and unmanaged psychiatric diagnosis, specifically if the participant disclosed a mental health issue that was not being managed by a physician or allied health professional. See Appendix 11 for the study recruitment flyer.
4.3.3 Measures

4.3.3.1 Children’s assessment of participation and enjoyment (CAPE)

The CAPE (King et al., 2007) is a 55-item questionnaire that examines how children and youth (ages 6 to 21 years old) participate in leisure and recreation activities. The questionnaire examines five dimensions of participation: diversity (number of activities done), intensity (how often), with whom the activity is done, where the activity takes place, and level of enjoyment of each activity (King et al., 2007). The sum of scores is tallied per dimension and divided by the diversity of activities to yield a dimension score. Here, a higher score is indicative of increased participation. Psychometric properties reveal an internal consistency between $\alpha = 0.32$ and $\alpha = 0.76$; test-retest scores have been between 0.67 to 0.86 (Imms, 2008).

4.3.3.2 Self-efficacy questionnaire for children (SEQ-C)

The SEQ-C (Muris, 2001) is a 24-item questionnaire, in which participants are asked to rate their perceived ability to accomplish a task between 1 (not at all) to 5 (very well). The questions cover three domains of self-efficacy, namely social, academic, and emotional. In a sample of 373 adolescents, cronbach’s alpha was found to be between 0.85 and 0.88 (Muris, 2001). See Appendix 12 for the SEQ-C assessment.

4.3.3.3 Heart rate variability (HRV)

HRV measures were calculated for each subject using standard time and frequency domain parameters set out by the Task Force (1996). Time domain variables provide an overall measure of variability/complexity of interval times between heartbeats. Frequency domain measures describe the periodic oscillations of the heart rate signal, decomposed at different frequencies to reflect the power (magnitude) of sympathetic and parasympathetic systems in driving change in HRV (Task Force, 1996). Please see Table 4.1 for HRV measures.
Table 4.1 HRV variable definitions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDNN (ms)</td>
<td>Time domain</td>
<td>Standard deviation of intervals between heartbeats; global index of HRV</td>
</tr>
<tr>
<td>RMSSD (ms)</td>
<td>Time domain</td>
<td>Root mean square of successive differences; calculated through squaring the intervals between heartbeats</td>
</tr>
<tr>
<td>pNN50 (%)</td>
<td>Time domain</td>
<td>Proportion of heartbeat intervals that differ by more than 50 ms; indicative of parasympathetic activity</td>
</tr>
<tr>
<td>HF (ms²)</td>
<td>Frequency domain</td>
<td>Power (magnitude) in high frequency range, 0.15-0.4 Hz; indicative of parasympathetic activity</td>
</tr>
<tr>
<td>HFnu</td>
<td>Frequency domain</td>
<td>HF power in normalized units, as a ratio of the total power</td>
</tr>
<tr>
<td>Total power (ms²)</td>
<td>Frequency domain</td>
<td>Variance of all heartbeat intervals</td>
</tr>
</tbody>
</table>

Note: HRV variables defined above were adapted from the Task Force (1996)

4.3.3.4 Post-concussion symptom inventory (PCSI)

The PCSI is a 21-item self-report measure where symptom severity is rated on a scale of 0 (not at all) to 6 (severe) for symptoms that occur within physical, cognitive, emotional, and sleep domains (Appendix 4; Sady, Vaughan, & Gioia, 2014). Internal consistency has been found to range from 0.79-0.93 for the subscales and 0.94 for the total symptom score (Sady et al., 2014).
4.3.3.5 Godin Leisure-Time Exercise Questionnaire (GLTE)

The GLTE (Godin & Shepard, 1997) is a self-report measure that assesses weekly physical activity engagement by asking participants to indicate how many times per week they engage in strenuous (heart beats rapidly), moderate (not exhausting) or mild exercise (minimal effort). Reliability has been documented as moderate, $r=0.62$ (Helmerhorst, Brage, Warren, Besson, & Ekelund, 2012). See Appendix 13 for the GLTE tool.

4.3.4 Intervention

The MBY intervention took place in a group setting at a children’s rehabilitation hospital. All sessions were carried out by the second author, who is both an occupational therapist and certified yoga instructor (RK). The components of each MBY session were as follows:

- **Mindfulness meditation:** Attention was anchored on the sensations of breathing and the body, training the mind to notice when distraction and thinking occurs, and to bring the attention back to noticing the breath in the present moment. Thoughts, feelings/emotions, and physical sensations are regarded as passing states (impermanent). Participants were encouraged to use mental noting (i.e., labeling thoughts at “planning”, “remembering”, “thinking” without attaching value or judgement) to aid in disengaging from rumination and returning to the breath.

- **Physical yoga postures:** All postures were novice and included standing, supine, prone and seated stances. Modified postures were offered based on participant ability and limitations.

A full breakdown of the eight MBY sessions can be found in Appendix 14.

4.3.5 Procedure

All participant data collection took place at a children’s rehabilitation hospital, carried out by the primary author (MP). Pre-intervention, a demographic information form was used to collect information regarding age, sex, concussion history, and history of mental health issues (Appendix 15). The CAPE, SEQ-C, PCSI, GLTE and a 24-hour HRV recording were collected at pre-, post- and 3 months following the MBY intervention. In absence of a baseline for concussion symptoms and physical activity, participants were instructed to reflect on a perceived
baseline at the time of pre-intervention data collection; this was collected for the PCSI and GLTE. A participant satisfaction survey (Larsen, Attkisson, Hargreaves, & Nguyen, 1979; Appendix 16) was also administered post-intervention. A 45-minute HRV recording was also collected during each of the eight MBY sessions. The Polar RS800CX watch and chest strap (Appendix 5; RS800cx; Polar Electro, Kemple, Finland) was used to collect HRV. See Appendix 17 for the study’s procedural flowchart.

4.3.6 Data Collection and Analysis

HRV data was analyzed with Kubios software, version 2.0 (Biosignal Analysis and Medical Imaging Group, Kuopio, Finland), in which a very-low filter was used to remove ectopic heartbeats/noise. Window frames were 300 seconds, 50% overlap, 4 Hz interpolation rate. Power spectral density analysis, via the fast fourier transform, was used to derive frequency domain variables (Table 4.1). These filtering and analysis techniques are in line with previous concussion research (Abaji et al., 2016; Hutchison et al., 2016). Due to the small sample size and case series design, it was most appropriate to describe trends in measures rather than apply inferential statistics (Carey & Boden, 2003). Visualization analysis was suitable for the following reasons: (1) low power increases Type I error, overestimating true effects (Button et al., 2013); and (2) case series methodology states that visualizations are the most suitable approach to gleaning information from preliminary, exploratory studies (Kooistra, Dijkman, Einhorn, & Bhandari, 2009). Line graph visualizations were explored to depict trends in occupation-based measures. Missing data within the HRV visualizations were a result of lack of attendance or the loss of data due to recording malfunction. Thus, dotted line graph visualizations with linear ‘line of best-fit’ trend lines were used to depict changes in HRV within each participant.

4.4 Results

Participants (N=8) were between the ages of 13-17 years old (female=5, male=3) with identified persistent concussion symptoms >4 weeks. Two participants (due to distance from hospital [N=1] and commencing university [N=1]) did not complete the study and their data was excluded from the analysis. Table 4.2 provides descriptive information on participants included in the study analysis (N=6).
4.4.1 Self-efficacy

Trends of increased self-efficacy (Figure 4.1) in the academic domain were seen across all participants from pre- to post-intervention, indicative of improved self-confidence in paying attention in class, improved ability to complete homework and asking teachers for help when needed. Trends in social self-efficacy were similar in that most participants experienced increases from pre-intervention to 3-month follow-up, reflective of increased self-reports in expressing their opinion, maintaining friendships and managing conflict. Finally, for most participants, trends in emotional self-efficacy also showed prominent increases from pre- to post-intervention, with additional gains shown at 3-month follow-up. Participants reported increased confidence in controlling one’s feelings, calming down, and not worrying. The other two participants showed initial increases from pre- to post-intervention, however, these returned to pre-intervention values at the 3-month follow-up.

Table 4.2 Participant demographic information and injury characteristics

<table>
<thead>
<tr>
<th>ID</th>
<th>Days post injury</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>History of concussion (N)</th>
<th>Mechanism of injury</th>
<th>Other interventions received currently</th>
<th>Medications</th>
<th>Main Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>102</td>
<td>201 days</td>
<td>16</td>
<td>Female</td>
<td>7</td>
<td>Sport</td>
<td>Chiropractor, Psychiatrist, Social Work</td>
<td>Yes; topiramate (headaches); sumatriptan (headaches)</td>
<td>Return to Sport; decreased amount of friends</td>
</tr>
<tr>
<td>104</td>
<td>98 days</td>
<td>16</td>
<td>Male</td>
<td>3</td>
<td>Sport</td>
<td>Athletic therapist, Psychologist</td>
<td>No</td>
<td>Pressure in head, foggy; headaches; paying attention</td>
</tr>
<tr>
<td>105</td>
<td>153 days</td>
<td>17</td>
<td>Female</td>
<td>1</td>
<td>MVA</td>
<td>Acupuncture, occupational therapy</td>
<td>No</td>
<td>Headaches; explaining injury to others; not able to do as much as prior to injury</td>
</tr>
<tr>
<td>106</td>
<td>30 days</td>
<td>16</td>
<td>Male</td>
<td>1</td>
<td>Syncope</td>
<td>Massage, occupational therapy, physical therapy</td>
<td>No</td>
<td>Headaches</td>
</tr>
<tr>
<td>107</td>
<td>117 days</td>
<td>16</td>
<td>Female</td>
<td>5</td>
<td>School</td>
<td>Massage</td>
<td>No</td>
<td>Missing dance; isolation; boredom</td>
</tr>
<tr>
<td>108</td>
<td>29 days</td>
<td>13</td>
<td>Female</td>
<td>2</td>
<td>Sport</td>
<td>Chiropractor, Cognitive behaviour therapist</td>
<td>No</td>
<td>Distracted at school; communicating with parents (always angry); communicating with friends</td>
</tr>
</tbody>
</table>
Note: a denotes that this participant had a post-injury mental health diagnosis (major depressive disorder). b denotes another participant with a pre-injury mental health diagnosis (generalized anxiety disorder).

4.4.2 Participation

Across the majority of domains of participation, no trends in “diversity”, “where,” “how often,” and “enjoyment” of activities were found. However, in the domain of “with whom,” trends of more isolated, individual activities rated at pre-intervention, increased to more social activities with friends and family at post-intervention and 3-month follow-up.
Figure 4.1 Primary outcome measure scores across pre-, post- and 3 months following MBY intervention. (A) Self-efficacy academic, social and emotional domain scores. (B) Trends in HRV within the 45-minute MBY sessions and across the 23-hour recording across pre-, during MBY sessions, post- and 3-month follow-up. Participant MBY105 was removed from the MBY session visualizations as she missed more than half the sessions.
4.4.3 Heart rate variability
Within time-domain variables, trends of increased HRV were found across the 8-week MBY intervention; SDNN appeared to gradually increase from the first to last session of MBY (Figure 4.1). Other time-domain measures revealed a mix of directionality in trends (pNN50: 3 increased, 2 decreased and 1 remained the same; RMSSD: 3 increased, 2 decreased and 1 remained the same). Within frequency domain variables, HFnu (indicative of parasympathetic activity) also showed trends of gradual increases from the first to last session of MBY (Figure 4.1). Across the 24-hour recordings, SDNN appeared to gradually increase from pre-intervention to 3-month follow-up.

4.4.4 Concussion symptoms
Trends of decreased symptoms on the PCSI were found following the MBY intervention (Figure 4.2). In the physical and cognitive domains, trends of considerable decrease post-intervention were found compared to pre-intervention and maintained at the 3-month follow-up. In the fatigue and emotional domains, trends of significant decrease were also found from pre- to post-intervention across all participants.

4.4.5 Physical activity
There appeared to be a potential interaction between type of physical activity and time when examining mild and strenuous exercise (Figure 4.2). Pre-intervention, elevated reports of mild exercise were seen (e.g., easy walking), with no reports of strenuous exercise, compared to perceived baseline ratings. At post-intervention, trends of mild and strenuous exercise went in opposite directions, whereby mild exercise appeared to decrease and strenuous exercise appeared to increase and this trend was maintained at three months. Moderate forms of exercise (e.g., dancing) followed the same trajectory, in which considerable increases were observed from pre-intervention to the 3-month follow-up.

4.4.6 Feasibility: Data collection and participant compliance and satisfaction
Participants were expected to attend a total of 11 sessions (three assessment sessions [pre-, post-, and 3 month follow-up] and eight MBY intervention sessions), which were all administered at
the children’s rehabilitation hospital. All six participants attended the three assessment sessions and in the time frame required by the study. Data collection during the three assessment sessions took approximately 1 hour, with no participants expressing difficulty or fatigue in completing the self-report measures. The intervention sessions took 1.5 hours (to collect heart rate monitors and re-suit with new monitors before MBY session commenced); no participants refused heart rate data collection. It is worth noting that no participants needed to leave, take a break or modify postures from all MBY sessions. Attendance ranged from 100% to 50% across sessions: 83-100% for 5/8 sessions; 50-67% for 3/8 sessions. Reasons for lack of attendance were unrelated to intervention engagement and included: graduation; exams/assignment; out of town for vacation. Participants completed satisfaction surveys post-intervention with the following results: 6/6 rated “excellent” on quality of MBY; 4/6 rated MBY as “meeting all their needs” (2/6 said “most of their needs were met”); 6/6 would “recommend MBY to family or friends in need of similar help”; MBY “helped somewhat” (3/6) and “helped a great deal” (3/6); 5/6 would “definitely” do MBY again.
(A) Concussion symptoms

(B) Type of physical activity
Figure 4.2 Secondary outcome measure scores across pre-, post- and 3 months following MBY intervention. (A) Concussion symptom severity scores in physical, cognitive, emotional and fatigue domain scores across time. (B) Physical activity ratings of mild, moderate and strenuous exercise across time.

4.5 Discussion

While preliminary, there appeared to be trends of improved self-efficacy, decreased symptom reports, and improved physical activity repertoires following MBY that were maintained or improved at the 3-month follow-up. HRV also appeared to improve, with slight increases within the eight MBY sessions and across pre-intervention, post-intervention and 3-month follow-up time points. It is important to note that conclusions cannot be drawn from improvements seen in this study as persistent concussion in youth can resolve as a function of time. Further, due to the pilot nature of this study, youth were not excluded if they were receiving other interventions concurrently. These factors could have made a positive impact on the youths recovery or augmented improvements from MBY. From a feasibility standpoint, this study demonstrates replicable process for a larger-scale trial; data collection time/methods and participant attendance and satisfaction are reflective of good clinical uptake for this population. However, this study does provide a foundation for a potentially promising intervention for this population.

In the cost-constrained healthcare environment of treating youth concussions, developing novel and feasible intervention protocols are crucial to: (1) addressing the needs of this complex population; and (2) developing service delivery models that focus on cost-effective specialized treatment. Group interventions may address these gaps. While not the focus of this pilot work, group intervention settings enable participants to learn from one another, creating a social atmosphere of shared experiences. In fact, it has been found that some are more likely to engage in therapy in groups compared to when they are in individual sessions (Henderson & Pehoski, 2006). Within the comments collected in the participation satisfaction survey, participants alluded to these benefits in stating that the setting of a group intervention “helped me get cleared to walk/ride a bike. It also is a good program for people with concussions to know they aren’t alone… helped calm down any anxious feelings”. The feasibility of this intervention may also serve to prompt occupational therapists to expand their scope of practice to include training in MBY. Again, given the limited sessions clinicians are given within the consultative model, this
intervention approach can begin to address some of the current practice limitations to ensure this population is supported in multiple domains of their life (i.e., safe physical activity, psychosocial function, development of coping strategies). With “occupation” at the core of client-centred practice, occupational therapists are well suited to expanding their skillset and moving the field of treatment in persistent youth concussion forward.

Given the exploratory nature of this study and the vulnerable population of youth, clinicians, researchers and ethics specialists decided on a protocol that was minimally intensive and time consuming (to decrease the risk of symptom exacerbation). Here, authors modified the intensity and frequency of this MBY intervention from adult recommendations of 2 hours, 1x/week, for 10 weeks to 45 minutes, 1x/week for 8 weeks. In context of the time commitment to come to the hospital for 11 sessions, this protocol was feasible and realistic. Given that this study was carried out in the province of Ontario, Canada, evidence-informed guidelines were used to align with the conservative nature of treating youth with persistent concussion (Ontario Neurotrauma Foundation, 2014). As such, this protocol was also modified to suit the needs of this population (i.e., fatigue, anxiousness, significant physical deconditioning).

Persistent symptoms may be maintained by ‘real-life’ functional factors (e.g., changes in academic performance, participation in leisure activities) which extend beyond the pathophysiology of the injury (Ellis et al., 2015; Stein et al., 2016). Consequently, youth with persistent concussion symptoms likely experience difficulties in verifying and evaluating their own abilities due to changes in volition (O’Brien, 2009) and daily occupational repertoire (Paniccia & Reed, 2016). This may explain the change in self-efficacy seen across academic, social and emotional domains. Improved self-efficacy observed post-intervention and maintained at the 3-month follow-up may be reflective of a renewed sense of self-assurance. Mirrored in a pilot study for adults with persistent concussion symptoms, self-efficacy and quality of life improvements were found following mindfulness-based stress reduction, although no long-term follow-up data was collected (Azulay et al., 2013). MBY may have acted as a source of evaluative feedback, producing anticipatory benefits in re-integrating previous forms of activity.

There were no significant trends of change in participation and enjoyment in daily leisure activities. However, MBY was administered in a group setting in which youth had the opportunity to consistently see other youth going through the same experiences. Given the
possible links between participation and social roles, it may be that patterns of participation in activities are not as sensitive to change as the social roles that are tied to them. However, one study showed that in a sample of 16-18 year old youth experiencing concussion symptoms one year or more following the injury, there were significant decreases in daily activities such as cooking and baking, as well as social activities such as being in a study circle or going to the movies (Jonsson & Andersson, 2013).

This pilot study found preliminary trends that HRV improved over the course of the eight MBY sessions and pre-post intervention. Altered autonomic regulation is believed to be due to an uncoupling between the sympathetic and parasympathetic branches of the ANS and the heart (Leddy et al., 2007; Willer & Leddy, 2006). It is still unclear if this result reflects an appropriate reaction to concussion as a stressor or if it exceeds typical neurophysiological responses in creating a more detrimental state for the individual. The trend towards improved HRV in this study suggests that safe physical activity can enable this change. In fact, recent shifts in managing persistent concussion have suggested that low-intensity, mind-body interventions (without exacerbation of symptoms) may assist with autoregulatory function (Leddy et al., 2007; Willer & Leddy, 2006), and can alleviate the occupational costs associated with inactivity and prolonged rest (Paniccia & Reed, 2016). However, as mentioned, conclusions cannot be drawn in that youth had varied forms of restrictions and participation in other interventions, which could have played a role in these physiological findings. These results warrant further research.

This study also illustrated trends of change in secondary outcomes such as post-concussion symptoms and physical activity repertoires. It is important to note that MBY does not explicitly address post-concussion symptoms (i.e., no direct discussion was targeted at symptom experiences across the intervention sessions), however, reports of decreased symptoms were found across all domains. This is a positive finding as it highlights the need to consider more functional, and occupation-based approaches in enabling recovery for this population, rather than the pervasive attention on symptomatology. Not surprisingly, fatigue and emotional domains showed slight increases from post-intervention to the 3-month follow-up, and this may be due to fact that these two domains are characteristic of the lasting psychosocial sequelae seen in persistent concussion issues (McCarty et al., 2016). Finally, the positive changes observed in physical activity repertoire were also promising. Whether or not MBY acted as a safe catalyst to re-integrate previous forms of activity or if the effect of time contributed to symptom resolution
is still unclear. Nonetheless, youth did not experience symptom exacerbations and this is significant because traditionally, youth with persistent concussion symptoms are advised to avoid engaging in cognitive and physical activity while still symptomatic, even though engaging plays a strong role in the mood and lifestyle of youth (Bloom, 2004).

4.6 Limitations and Future Research

This study was a descriptive analysis of a small, repeated measures case series, thus findings cannot be generalized to the larger population of youth with persistent concussion symptoms. The limitations of this study are related to the testing environment and outcome measurement. Authors did not account for the social environment in which MBY was carried out (i.e., group-based setting). For example, youth were instructed to arrive 30 minutes before the start of each MBY session to return their HRV equipment and be suited with new equipment. During this time, youth occupied the same space with opportunities to talk about their day or their experiences, which may have played a role in the findings. With older athletes who have sustained a concussion, a social context in the form of injury support groups, has demonstrated positive psychological effects (Bloom, 2004). Secondly, neuropsychological assessment was not employed in this study and would have made a significant contribution, as attentional control (i.e. sustained attention) is a key component to the mindful training within MBY. Given the limited resources and diverse array of measures collected, this additional consideration was not feasible. Taken together, future research including a control group, and measures that account for social interaction and potential neuropsychological gains, would enable enhanced rigor in exploring the potential of this intervention further.

4.7 Implications for Occupational Therapy Practice

In the context of evidence-informed recommendations on the optimal level of rest, a “sensible approach” has been recommended which involves a gradual re-integration back to previous forms of activity (Stein et al., 2016). MBY is sensible as it is a biopsychosocial approach that marks a significant shift away from the focus on symptoms. Further, Green et al. (1997) explain that in order “to live a functional daily life, they need to accept the symptoms.” In this study, no data were collected (with exception of HRV) during the 8-week intervention. Here, MBY may act as a form of “safe doing” where youth can be engaged in something that targets both physical
and psychosocial aspects, in a way that allows them to establish coping mechanisms for their current symptoms, but does not result in exacerbation. Our findings have the following implications for occupational therapy practice:

- MBY has potential as a clinical intervention for youth with persistent symptoms as it provides low-intensity exercise, along with training on acceptance of the present moment.
- MBY supports occupation-based rehabilitation in building self-efficacy in key domains of academic, social and emotional functioning.
- Group-based settings may be a feasible way to offer MBY for youth continuing to recover from concussion.
4.8 References


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Chapter 5
The Dove-Hawk Model of Youth Concussion

5 The Dove-Hawk Model: Re-thinking Occupational Performance

This chapter presents a novel, conceptual model anchored in the constructs of stress adaption and occupational performance, within the scope of occupational therapy practice. Aligned with the BPS approach introduced within this thesis, this model was developed to expand on the constructs of stress and adaptation by considering the potential spectrum of youth who experience prolonged recovery from concussion. Here, this model outlines the various profiles of youth who experience persistent concussion symptoms, common occupational performance issues and a consideration for the array of environments that play a key role concussion recovery. Finally, this chapter concludes with considerations for individualized rehabilitation interventions.

An abbreviated version of this chapter was published within the Canadian Journal of Occupational Therapy. This journal provides a forum for rehabilitation clinicians to disseminate scholarly commentaries/theory development on novel clinical topics across an array of clinical conditions within the scope of occupational science and occupational therapy.


5.1 Introduction

Concussion, also known as a mild traumatic brain injury (mTBI), is one of the most common causes of head trauma in children and youth, resulting in more than 100,000 emergency department visits each year for school-aged children in the United States. In fact, approximately 1 in 220 pediatric patients are diagnosed with concussion in the emergency department every year (Meehan & Mannix, 2010). In a high school setting, concussions represent approximately 9% of injuries (Gessel, Fields, Collins, Dick, & Comstock, 2007). According to the 4th International Sport Concussion Consensus Statement, concussion is caused by biomechanical
forces to the head, neck or body, resulting in pathophysiological changes to the brain (McCrory et al., 2013). Concussion results in a variety of non-specific symptoms, which include physical (e.g. headache, dizziness, nausea), cognitive (e.g. mental fog, difficulty concentrating and remembering), emotional (e.g. sadness, anxiety, irritability) and sleep-related issues (e.g. trouble falling asleep, sleeping too much/too little; McCrory et al., 2013). Unfortunately, 20-30% of youth experience persistent concussion symptoms, which may last weeks, months and even years following the injury (Barlow et al., 2010; McCrory et al., 2013). The World Health Organization (World Health Organization, 2010) characterizes persistent concussion symptoms as the prolonged experience of the aforementioned symptoms; they are deemed “persistent” as they extend beyond the normal range of recovery in a youth population (McCrory et al., 2013). While epidemiological research has validated the presence of post concussion syndrome in a pediatric population (Barlow et al., 2010), little is known on how to effectively manage this subset of youth who experience persistent concussion symptoms and the related prolonged challenges in their daily occupations.

5.2 Theoretical framework

The concussion community (e.g. clinicians, researchers) has described concussion and its subsequent recovery as heterogeneous; that is, no one injury is the same and certainly, no one youth is the same in how they recover. Models of occupational therapy practice suggest that one’s occupational performance can be influenced by person (e.g. coping strategy, emotions, motivation), occupation (e.g. role as a student, friend, sibling), and environment (e.g. family support, school accommodations, social networks) factors (Law et al., 1996). When managing concussion within youth, further consideration of the person and the environment in which they live may provide insight on: (1) the differential spectrum of profiles that exist amongst youth who have experienced a concussion; and, (2) how these profiles can support individualized, and optimal approaches to rehabilitation. The purpose of this commentary is to provide a perspective on how the management of persistent concussion symptoms amongst youth can be improved by considering individual profiles. The concept of stress from an evolutionary perspective (Korte, Koolhaas, Wingfield, & McEwen, 2005) will be used to provide the foundation for the Dove-Hawk Model of Allostatic Load for Youth with Persistent Concussion Symptoms. This model aims to contextualize challenges associated with concussion recovery by considering person and environmental factors that influence occupational performance. This commentary concludes with
potential rehabilitation approaches suited to differential profiles of youth with persistent concussion symptoms. An activation approach will be proposed for those youth who have not made attempts at returning to activity. Conversely, a censoring approach will be proposed for youth with high incentives to return to activity swiftly.

5.2.1 Concussion as ‘allostatic load’ and return to activity as ‘allostasis’

Concussion is known as the ‘invisible injury’; typical neuroimaging techniques do not yield positive findings (Lee & Newberg, 2005; Prabhu, 2011) nor can the external community see the actual injury (in contrast to a visible musculoskeletal injury such as a broken arm or swollen ankle). Thus, concussion is known to be a functional injury, commonly resulting in both physical and cognitive challenges that make it difficult to participate in one’s daily activities and routine. Concussion marks a significant shift in a youth’s abilities and impacts their capacity for occupational performance and engagement. For example, participating in school-related, social and extracurricular occupations may be more difficult to engage in based on symptoms and activity restrictions set out by the youth themselves, parents and health care professionals. Taken together, concussion is experienced as a stressful event, which directly impacts occupational performance. This stressful event, or a concussion, can also be referred to as allostatic load. Allostatic load can be defined as the cost of returning to pre-injury occupations due to a lack of resources or when resources are insufficiently managed (Korte et al., 2005). Specific to concussion, specific examples of ‘a lack of resources’ could be not having access to information regarding safe return to activity; or not being able to communicate regularly with physicians or allied health professionals on proper management strategies. An example of ‘insufficient use of resources’ could include a youth receiving inadequate information on how to manage their concussion or the youth attempting to return to school or sport too soon despite evidence-informed guidelines and recommendations. Allostasis, on the other hand, is the active process of achieving recovery; trying to engage in desired activities of daily life despite changing circumstances (Korte et al., 2005). In other words, working towards allostasis is about promoting the balance between gradually returning to activity and incorporating rest when needed. Recovery from a concussion involves the resolution of post concussion symptoms and a youth’s ability to achieve pre-injury levels of occupational performance. It is this recovery that would indicate allostasis. The question of ‘what is it that influences how youth respond to allostatic load and progress towards allostasis or recovery?’ is pervasive amongst health professionals,
educators, sport coaches, parents and youth dealing with concussion. Perhaps answers can begin to be elucidated by considering the impact of environmental conditions and behavioural profiles.

5.2.2 The spectrum of youth with persistent concussion symptoms

Behavioural profiles following concussion in youth can be understood by adapting dove and hawk profiles from evolutionary research (Korte et al., 2005), which conceptualizes allostatic load by considering how behavioural profiles and environmental factors influence occupational performance. Understanding this subset of differential behavioural profiles (i.e. passive dove and active hawk) is an initial first step to parsing out this heterogeneous population and the factors that might influence the ability of youth with persistent symptoms to experience recovery (symptom resolution and return to meaningful activity). Differences between dove and hawk profiles from an evolutionary perspective (e.g. behaviour, coping style, environment) are presented in Table 5.1.

Table 5.1 Dove and Hawk Profiles in Animal-based, Evolutionary Literature

<table>
<thead>
<tr>
<th>Evolutionary Characteristic</th>
<th>Dove</th>
<th>Hawk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Behavioural strategy</strong></td>
<td>Freeze-hide</td>
<td>Fight-flight</td>
</tr>
<tr>
<td><strong>Coping style</strong></td>
<td>Reactive</td>
<td>Proactive</td>
</tr>
<tr>
<td><strong>Emotional state</strong></td>
<td>Non-aggressive and cautious</td>
<td>Aggressive and bold</td>
</tr>
<tr>
<td><strong>Biological role</strong></td>
<td>Adopts strategy to avoid danger</td>
<td>Establishes and defends territory</td>
</tr>
<tr>
<td><strong>Environmental exploration</strong></td>
<td>Cautious and thorough</td>
<td>Fast and superficial</td>
</tr>
<tr>
<td><strong>Energy metabolism</strong></td>
<td>Energy conservation</td>
<td>Energy consumption</td>
</tr>
<tr>
<td><strong>Body damage</strong></td>
<td>Low risk</td>
<td>High risk</td>
</tr>
<tr>
<td><strong>Costs of adaptation</strong></td>
<td>• Anxiety</td>
<td>• Impulse control issues</td>
</tr>
<tr>
<td>(Allostatic load)</td>
<td>• Insomnia</td>
<td>• Chronic fatigue</td>
</tr>
<tr>
<td></td>
<td>• Infection</td>
<td>• Inflammation</td>
</tr>
</tbody>
</table>

**Note:** This table was adapted from Korte et al. (2005)
5.2.2.1 The passive dove profile

*Doves* have been described as having a passive approach to managing allostatic load. In evolutionary literature, *doves* are more detail-oriented about the decisions they make, considering a multitude of outcomes and their associated risks (Korte et al., 2005). *Doves* are more aware of their surroundings and cautious about engaging in potentially dangerous activities. For youth who display passive *dove* profiles following concussion, the expected behavioural profile might include a conditioned fear-response where activities that they were once able to do with ease (e.g. complete a homework assignment in 1 hour) are associated with a risk of failure. Thus, the youth may completely retreat from engaging or trying the task, even when it may be safe to do so. Another aspect of this profile may be the focus on symptoms in making decisions about when to commence or terminate participation in meaningful activities.

For example, part of a youth’s pre-injury activity repertoire might have been to run for 20 minutes a day. A youth with persistent symptoms, for example, may have a mild headache and decide to avoid running that day or completely remove running from their daily routine. The perpetual focus on symptoms that have lasted well beyond the typical recovery period may induce a state of fear for youth. Thus, these youth may appear anxious, nervous and hesitant to re-engage in pre-injury occupations. This profile may be disadvantageous to achieving allostasis (i.e. balance between trying to engage in activities and pulling back when a break or rest are needed), which may further limit them from achieving recovery. For example, prolonged rest amongst youth, and as a result, significant withdrawal from school or sport activities may extend recovery periods even further (Schneider et al., 2013; Thomas, Apps, Hoffmann, McCrea, & Hammeke, 2015). The notion of ‘learned helplessness’ may become apparent in this profile, in which youth may come to perceive themselves as being unable to perform the way they used to.

Youth who are cautious in the direction of complete avoidance may be at risk of developing secondary mental health issues such as anxiety and depression (Maller et al., 2010). Further, prolonged amounts of rest may also lead to mental and physical deconditioning (Thomas et al., 2015), making the return to school and physical activity even more daunting.

With respect to occupational performance, the passive *dove* profile can significantly influence how youth perform in their school and sport environments. They may experience challenges returning to school, taking on a full course load, completing homework after school and engaging in extracurricular activities (DeMatteo et al., 2015; Schneider et al., 2013). This overall
decrease in occupational engagement can be reflected in prolonged absenteeism and a sense of heightened anxiety in meeting school-related deadlines. Youth with this profile may take longer to complete homework and assignments or may require mental breaks throughout the day to re-mobilize their cognitive reserve. For youth involved in extra-curricular activities after school (e.g. sport, dance, band), a passive approach may be to terminate participation in the occupation to avoid the cost of sub-optimal occupational performance. Taken together, the passive dove profile has a heightened awareness of the many factors that may influence their occupational performance. However, this additional caution may prolong return to activity and ultimately, protract their concussion recovery. The passive dove profile is illustrated in Table 5.2.

5.2.2.2 The active hawk profile

Compared to doves, evolutionary literature has described the hawk as having an active approach to allostatic load. Hawks are more aggressive in their approach, drawing on their flight-or-fight response (i.e. increased sympathetic activation to confront danger or to flee from the environment). In this way, hawks are high risk-takers who are more active in their approach to allostasis. Active hawks do not necessarily consider the consequences of engaging in dangerous activity (Korte et al., 2005). Thus, active hawks may gain gratification in the short-term, but ultimately experience long-term consequences. For youth who display active hawk profiles following concussion, the expected behavioural profile might include a rigid approach to returning to meaningful activity. Youth may have high expectations for themselves in being able to engage in the occupations they did prior to the concussion and may not allow sufficient time to approach recovery in a stepwise, gradual nature. Youth with an active profile may attempt to return to school shortly after the injury and may not make attempts to communicate with teachers and principals regarding modifications and accommodations. Thus, the youth may return to pre-injury occupations prematurely even when it may not be safe to do so. While the youth may be satisfied with their early attempts to return to pre-injury occupations, they may ultimately experience a cost in occupational performance in the long-term. For example, the attempt to return prematurely may result in the youth feeling overly fatigued at the end of the day, resulting in the potential for more symptoms that are more severe and for a longer duration. Youth with this profile may ignore the presence or severity of their symptoms, thus exhausting all cognitive and physical resources to achieve their goals. For example, a youth may return to full contact sport shortly following injury and may expect a high level of occupational performance during
games. Disappointment in not achieving previous levels of occupational performance may lead the youth to display feelings of anger or irritability. This active and rigid attempt may also be disadvantageous to establishing allostasis. Premature return to activities following concussion has been shown to prolong recovery and may result in an increase and severity in symptoms (Reed et al., 2015). The associated risks of this profile include a risk of re-injury and significant energy depletion from exceeding one’s personal limits.

The active hawk profile has significant effects on occupational performance in school and other desired domains. Youth may display ‘presenteeism’ in school in which high motivation allows them to be physically present for a full day but their symptoms may prohibit them from performing at pre-injury levels (i.e. difficulty concentrating and remembering school material, challenges with tolerating long classes). Borrowed from work and mental health literature, the concept of presenteeism speaks to the inability to fully engage in required daily tasks due to mental fog, anxiety and burn-out (Johns, 2002). For youth involved in extra-curricular activities after school (e.g. sport, dance, band), an active approach may be to fully engage in all activities at the cost of exhausting all cognitive and physical resources, leading to an increase and/or exacerbation in symptoms. In summary, the active hawk profile has a high incentive to return to activity and may be willing to accept the potential risks of re-injury and extreme fatigue. This profile, like the passive dove, will still ultimately lead to prolonged recovery and may result in an exacerbation of concussion symptoms. The active hawk profile is illustrated in Table 5.2.

5.2.2.3 A Variety of environments: considering healthcare, family, school and social influences

A variety of environments play a key role in influencing concussion recovery amongst youth. The breadth of environments (e.g. school, parents, friends, healthcare professionals) that influence recovery in youth concussion underscore the importance of looking at youth concussion with a holistic rehabilitation lens. These environmental factors can include, but are not limited to, interactions with healthcare professionals, parent perceptions, school environment, and support from social networks (e.g. friends, sports team). With respect to healthcare environments, the awareness of youth concussion has increased in the last decade, with multimodal approaches to assessment (i.e. subjective symptom reports and objective physical and neurocognitive measures) and multidisciplinary intervention as the cornerstone of concussion management (Reed et al., 2014). However, there remains inconsistency in the
definition, diagnosis and how these assessment and management approaches are applied across healthcare disciplines. These inconsistencies can result in youth receiving mixed messaging on how to minimize and resolve post concussion symptoms, which impact when and how to return to activities safely. For example, youth may receive strict recommendations to refrain from engaging in physical activity in order to avoid symptom exacerbation even months following the injury. As mentioned earlier, prolonged rest in the chronic phases of the injury may not be beneficial for the youth from a mental health perspective (Schneider et al., 2013; Thomas et al., 2015). The school environment is another critical environment influencing concussion recovery. As youth spend the majority of their day in school, the level of understanding and compassion of teachers and school staff can play a critical role in how the youth re-integrates to their pre-injury school routine and course load, and the success of this re-integration. Within the province of Ontario, concussion policies and protocols within schools are starting to be implemented (Ontario Ministry of Education, 2014). Unfortunately, these policies are broad in nature, with varying levels of administrative support for teachers to get access to relevant resources. Teachers may be unsure about the level of accountability they play in managing concussion, which in turn, may result in the youth’s own confusion about who to approach regarding school accommodations.

Family environments and parental dynamics play a crucial role in how the injury is perceived by the youth. Parents are presented with their own challenges in finding ways to support and care for their child. For example, some parents may outwardly express their anxiety to their child about attempting to return to previous occupations, with a constant focus on monitoring symptoms to avoid risk of re-injury. Conversely, other parents may not fully understand the gravity of concussion, deflating the severity of concussion and encouraging a swift return to pre-injury occupation. Finally, social networks may also play a role in concussion recovery. The limited occupational repertoire experienced by the youth with concussion is often associated with a decreased opportunity to connect with friends in a variety of social settings (e.g. going to loud parties, movies, busy malls). Similar to parental responses, friends may underestimate the needs of the youth with concussion, putting pressure to return to previous occupations. Friends may also “forget” to extend the invite when the youth with concussion has been missing from the friend group for a prolonged amount of time. The array of understanding and responses from healthcare professionals, teachers, family and friends can be inconsistent resulting in confusion
and frustration of the youth on how to best manage the concussion and return to previous occupations, thus contributing to *dove* or *hawk* profiles (Table 5.2).

### Table 5.2 Descriptive Profiles of Passive Doves and Active Hawks in Youth Concussion

<table>
<thead>
<tr>
<th></th>
<th>Passive Dove</th>
<th>Optimal Recovery</th>
<th>Active Hawk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behaviour</td>
<td>• Fear-response</td>
<td>• Understand personal strengths and boundaries in returning to activity</td>
<td>• High incentive to return to activity prematurely</td>
</tr>
<tr>
<td></td>
<td>• Pain/symptom-focused</td>
<td>• Balance between activity and rest</td>
<td>• Rigidity, high expectations</td>
</tr>
<tr>
<td></td>
<td>• Prolonged rest/inactivity</td>
<td>• Return-to-activity is stepwise and gradual</td>
<td>• Irritable and upset</td>
</tr>
<tr>
<td></td>
<td>• Hyperaware, cautious</td>
<td>• Realistic goal-setting</td>
<td>• Increased fatigue</td>
</tr>
<tr>
<td></td>
<td>• Anxious and nervous</td>
<td></td>
<td>• High risk</td>
</tr>
<tr>
<td></td>
<td>• Low risk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Associated Risks</td>
<td>• Prolonged recovery</td>
<td></td>
<td>• Prolonged recovery</td>
</tr>
<tr>
<td></td>
<td>• Secondary mental health issues (anxiety, depression)</td>
<td></td>
<td>• Increased risk of re-injury</td>
</tr>
<tr>
<td></td>
<td>• Mental and physical deconditioning</td>
<td></td>
<td>• Fatigue/Burn-out</td>
</tr>
<tr>
<td></td>
<td>• Learned helplessness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional Performance</td>
<td>• Overall, decreased function</td>
<td>• <em>In school:</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• <em>In school:</em></td>
<td>o Able to complete course work and assignments with modifications</td>
<td>• Prolonged presenteeism</td>
</tr>
<tr>
<td></td>
<td>o Prolonged absenteeism</td>
<td>• <em>In extracurricular activities (e.g. sport):</em></td>
<td>o Difficulty achieving pre-injury academic</td>
</tr>
<tr>
<td></td>
<td>o Difficulty returning to full course load</td>
<td>o Engages in sport based on stage of return to play guidelines</td>
<td>performance</td>
</tr>
<tr>
<td></td>
<td>• <em>In extracurricular activities (e.g. drama club):</em></td>
<td></td>
<td>• <em>In extracurricular activities (e.g. dance):</em></td>
</tr>
<tr>
<td></td>
<td>o Not involved or</td>
<td></td>
<td>o Decreased performance (e.g. reaction time,</td>
</tr>
<tr>
<td></td>
<td>o Involved in limited ways (i.e. practice only, watches rehearsals)</td>
<td></td>
<td>coordination), fatigue</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>o Frustration with sub-par performance</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health Care Environment</td>
<td>• Access to concussion knowledge and information on management strategies</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Consistency and communication with physician and allied health professionals</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Information re: prolonged rest and when to return to activity (e.g. school and extracurricular activities)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>School Environment</td>
<td>• Involvement and understanding of teachers and school staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Access to resources to ease return to full day of school and full course load (i.e. quiet space for breaks, alternate spaces to complete work if needed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Social friend networks may magnify or de-emphasize severity, altering expectations of the youth with concussion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family Environment</td>
<td>• Parental levels of anxiety and worry about amount of rest youth should receive and when they can start to re-integrate to pre-injury activities</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Parental perceptions of the severity of the injury (e.g. may de-label injury and encourage return to activity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Parental involvement in youth’s schedule (e.g. may micromanage daily activities and focus on symptoms or may encourage early return to activity)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.3 The Dove-Hawk Model of Allostatic Load for Youth with Persistent Concussion Symptoms

The Dove-Hawk Model of Allostatic Load for Youth with Persistent Concussion Symptoms is a conceptual model that illustrates the spectrum of passive and active profiles in youth with persistent symptoms. The normal distribution curve represents the relationship between the amount of allostatic load and occupational performance (Figure 5.1). In the optimal recovery zone (between the dotted lines), the allostatic load is being managed appropriately and desired occupational performance can be achieved. Beyond those boundaries are variations of passive dove and active hawk profiles, in which the cost to having those profiles results in decreases in occupational performance. It is important to note that these profiles are meant to fit across a spectrum of individual variability; that is, youth with persistent symptoms do not dichotomously exist in the passive dove or active hawk profiles. Rather, these profiles illustrate the ends of the spectrum where the most difficulty in establishing allostasis may be present. As a youth moves from either end towards the center of the model, they become closer to adequate management of the concussion (i.e. persistent concussion symptoms), thus increasing their occupational performance. Viewing youth concussion as a form of allostatic load enables flexibility because the aim is to find the right balance between attempts at returning to activity and taking the necessary precautions to ensure the return is safe. For example, in the optimal recovery profile (i.e. between the dotted lines of the model), youth have a good understanding that a gradual stepwise return to activity would allow them to successfully return to previous occupations (see Table 5.2 for optimal recovery profile). For example, for a youth involved in competitive sport, this may include a gradual return to school with appropriate accommodations along with a gradual step-wise approach to returning to their sport. The Dove-Hawk Model of Allostatic Load for Youth with Persistent Concussion Symptoms can be used as a framework to guide different rehabilitation approaches based on the unique needs of youth across the spectrum of passive doves and active hawks. In this way, the goal of rehabilitation/intervention is to bring the youth closer to being able to manage the allostatic load while still being able to engage in activities (e.g. school, extracurricular activities, etc.).
5.3.1 Activation and censoring rehabilitation approaches

Activation and censoring approaches are represented in the model as approaches that enable youth to be activated to re-engage in activities or apply stepwise, censorship to engaging in activity, respectively. In this way, the goal of rehabilitation/intervention is to bring the youth closer to being able to manage the allostatic load while still being able to engage in meaningful activities (e.g. school, extracurricular activities, etc.). For passive doves, the consistent focus on symptoms may act as a barrier to re-engaging in previous occupations. Clinicians can employ strategies that facilitate “doing” in a safe manner for youth to reduce anxiety/build confidence. These strategies, depending on the youth, may include:

- Top-down management strategies that focus on self-management and functional goal setting (e.g. Cognitive Orientation to Daily Occupational Performance, CO-OP; (Dawson et al., 2009; Polatajko, Mandich, Miller, & Macnab, 2001).
- Active rehabilitation, which allows the youth to gradually build aerobic capacity in a safe, monitored environment and improve self-confidence with respect to return to activity (Gagnon, Galli, Friedman, Grilli, & Iverson, 2009; Reed et al., 2015).
• Mental health interventions (e.g. Cognitive Behaviour Therapy) that focus on re-building positive self-schemas (Potter & Brown, 2012).
• Daily Activity Logs where youth can compare what they planned and actually carried out, noticing patterns of success and challenge (Reed et al., 2015).

Conversely, censoring approaches still focus on “doing,” however place emphasis on creating personal boundaries and making realistic expectations about how to return to activity in the most effective way. These strategies may include:
• Education around energy conservation (i.e. prioritizing, pacing, planning, positioning) to avoid fatigue and long-term energy depletion (Reed et al., 2015).
• Education on creating modified learning plans in the classroom that offer flexibility in homework, assignment and test completion (DeMatteo et al., 2015; Reed et al., 2015).
• Positive mental imagery when the youth is frustrated about their performance (Gagnon et al., 2009).
• Mindfulness and relaxation-based training to focus on the present moment and reduce self-judgement (Azulay, Smart, Mott, & Cicerone, 2013; Reed et al., 2015).

5.4 Limitations and Future Directions

The Dove-Hawk Model of Allostatic Load for Youth With Persistent Concussion Symptoms marks a novel contribution to the field of youth concussion as it prompts a shift in how researchers and practitioners view this complex population and, further, offers targeted rehabilitation approaches that may be more suitable to a youth’s profile. However, this model is not without limitations. As it is currently presented, this model is limited because it applies a static label to the youth’s overall profile; that is, youth may display dove profiles when returning to school but are hawks when presented with opportunities to reintegrate into extracurricular activities, such as sport. The school and extracurricular environments may elicit differential responses from youth in what they feel they are capable of attempting. Further to this point, both hawks and doves have been presented as having some element of anxiety; however, the way in which anxiety drives responses to concussion recovery is different according to the profile. Doves might react to anxiety by avoiding an occupation, whereas hawks’ experience of anxiety may be reflected in internal pressure to perform occupations at pre-injury levels. This model also does not consider premorbid profiles. Prior to concussive injury, youth may already display
modified forms of doves or hawks; they may be generally anxious about their occupational performance in a variety of domains, or they may be risk takers in how they engage in daily occupations. These premorbid profiles likely play a significant role in how youth perceive their concussion and their subsequent recovery. Future development of the model may benefit from dove and hawk profiles according to environment and suggesting specific strategies/interventions, offering the youth a toolbox of resources to address their recovery holistically. This model also has implications for concussion policy. Within the school setting specifically, this model has the potential to act as an educational tool for teachers, principals, and policy makers. Mentioned earlier, current concussion policies are broad, leaving little direction on how to best support youth. Offering an understanding on how a youth’s occupational performance may be affected by the various person, occupation, and environment factors can shed insight on targeted classroom modifications and student accommodations, especially in the development of individualized educational plans.

5.5 Conclusion

The view that youth with persistent concussion symptoms are a heterogeneous population is valid but differential profiles may provide new insights into how clinicians, researchers, parents, youth and other stakeholders can enable optimal return to activity (i.e. activation and censoring approaches). The Dove-Hawk Allostatic Load Model for Youth with Persistent Concussion Symptoms provides a conceptual framework in describing the challenges that youth experience in returning to pre-injury activity following concussion. With the optimal goal being return to pre-injury activities, this model offers a functional approach to rehabilitation that considers the unique needs of the youth. Further clinically-based research on the identification and assessment of these profiles is warranted. In conclusion, this model proposition provides a description of passive dove and active hawk profiles in youth concussion with potential recommendations for how activation and censoring rehabilitation approaches may be suitable to facilitate optimal return to activity.
5.6 References


children who are slow to recover following sport-related concussion. *Brain Injury*, 23(12), 956–964. https://doi.org/10.3109/02699050903373477


https://doi.org/10.1080/13638490400022394


Chapter 6
Conclusion

6 Summary and General Discussion

6.1 Highlighting the Unique Youth Athlete

Sport participation can be beneficial, particularly during adolescence, resulting in enhanced physical literacy (Giblin, Collins, & Button, 2014), enhanced social communication and a greater ability to work with others (Eime et al., 2013), as well as superior higher order cognitive abilities such as executive functioning (Baile, 2005; Bailey et al., 2009; Lax et al., 2015; Paniccia, Urban, Mitchell, Seaton, & Reed, 2016; Rasberry et al., 2011). However, youth who participate in sport are nearly six times more likely to sustain a concussion, compared to their non-athletic counterparts (Browne, 2006). Zemek et al. (2017) revealed that over an 11-year period (2003-2013), there were approximately 176,000 pediatric visits for concussion in the emergency department in Ontario, with a 4.4 fold increase per 100,000. While the risk of concussive injury is significantly higher in youth athletes, the benefits of safe participation in sport appear to outweigh the risk of injury. The most recent 5th International Consensus Statement on Concussion in Sport (McCrory et al., 2017) stated the current state of the literature on concussion assessment and management has largely been limited by: (1) the focus on adult and collegiate populations; (2) lack of longitudinal studies and (3) inconsistency in the investigation of neurophysiological mechanisms following injury. This thesis directly addressed these gaps by investigating HRV in youth athletes between the ages of 13 to 18 years old across healthy, concussed and persistent concussion states. Further, a recent systematic review indicated the importance of managing youth uniquely, given that they are in a period of rapid neurodevelopment (Davis et al., 2017). Given that the Government of Canada (2017) has highlighted youth concussion as a serious public health concern, examining healthy, concussed and prolonged recovery samples is a foundational step to enhancing the clinical and research community’s knowledge on the physiological manifestation of this injury over time. Here, the understanding of baseline/healthy ANS function (via HRV) in the context of non-specific, concussion-like symptoms can provide information on how the concussion community can begin to interpret post-concussion changes. Using the BPS model as a conceptual model (Figure 6.1) to highlight the dynamic interactions between biological and psychosocial aspects of concussive
injury and recovery, this doctoral research revealed a promising area of future research (i.e. the exploration of physiological/HRV change over time in mild traumatic brain injury). Here, the continued exploration of physiological mechanisms of concussion in the context of everyday life stressors will be a key piece to elucidating the optimal assessment methods and in influencing youth-centred concussion management strategies.

Figure 6.1 The Biopsychosocial Model. Adapted from (Eklund & Tenenbaum, 2014).

This final chapter summarizes the key findings across Chapters 2, 3 and 4. Clinical relevance and contributions to the field of youth concussion and rehabilitation are offered while considering the dynamic interplay between physiological mechanisms, health outcomes, behavioural output and psychosocial stressors. This chapter concludes with a proposed future study, which incorporates both the findings and limitations across the three independent studies presented within this thesis.
6.2 Summary of Findings

Chapter 2 of this thesis explored the relationship between HRV and concussion-like physical, cognitive, emotional and fatigue symptom domains within a healthy sample of youth athletes. This study addressed objective 1 of this thesis: to describe natural variations in HRV in a healthy sample of youth athletes, when considering age, sex and concussion-like factors (symptom-reporting and concussion history). This cross-sectional study presented data on a large sample of healthy youth athletes (N=294, female=166 [56.5%], male=128 [43.5%]). Here, trends of daily concussion-like symptoms were found to be associated with reduced HRV, after considering differences in age, sex and concussion history.

Using multiple regression analysis, this study explored the influence of age and sex on HRV in healthy youth athletes; and, the relationship between HRV and baseline/pre-injury concussion symptom domains. Sex had a significant main effect whereby females had lower SDNN compared to males ($B = -0.071$, $SE = 0.033$, $p = 0.03$). This was also replicated with HF and total power; whereby females had lower values compared to males (HF: $B = -153.73$, $SE = 64.71$, $p = 0.019$; total power: $B = -0.203$, $SE = 0.08$, $p = 0.01$). Age was also significant ($B = 0.031$, $SE = 0.013$, $p = 0.023$) in predicting SDNN, whereby older participants had higher SDNN compared to younger participants. Regarding concussion-like symptoms, the cognitive domain was the only domain demonstrating a significant effect ($B = -0.021$, $SE = 0.009$, $p = 0.02$). Here, there was a negative relationship whereby youth who endorsed more cognitive symptoms, had lower SDNN. This finding was also replicated within the RMSSD measure ($B = -2.195$, $SE = 1.00$, $p = 0.03$). A notable finding was the significant interaction effect between PCSI total score and pNN50 as a function of sex ($B = 0.424$, $SE = 0.211$, $p = 0.04$). Here, the relationship between PCSI total score and sex was present in those who did not have a previous history of concussion. In females with no previous history of concussion, there was a positive association between PCSI total score and pNN50 whereby, increased concussion-like symptom reporting was associated with increased pNN50. The opposite was found in males with no previous history of concussion, whereby increased concussion-like symptom reporting was associated with decreased pNN50. This study provided the foundational context with which to explore HRV in a youth athlete population; here, the findings of variation in a physiological signal associated with daily concussion-like symptoms provide important insight to interpreting change following concussion.
Chapter 3 addressed objective 2, to explore the effect of concussion on HRV in youth athletes across the recovery trajectory; and objective 3, to examine the relationship between traditional, subjective self-report (concussion symptom reporting domains) and objective HRV measures across days post injury in youth athletes. This prospective, longitudinal matched control study presented data on 29 concussed athletes between the ages of 13 to 18 years old (females=21, males=8; mean age: 15 years old [±1.48], and 15 age- and sex-matched controls [total N=44]). Results revealed a main effect of days post injury, whereby HRV increased across days post injury. All concussion symptom domains (physical, cognitive, fatigue and emotional) had a significant main effect on HRV; concussed athletes who reported more symptoms had higher HRV and those who reported fewer symptoms had decreased HRV.

Utilizing a mixed modeling (random intercept, fixed main effects) approach to analysis, the effect of concussion on HRV along the recovery trajectory was examined, while considering post-concussion symptom domains and the comparison between concussed and control participants. A main effect of days post injury was found across HRV variables (RMSSD: $B=0.0001, p=0.02$; pNN50: $B=0.0009, p=0.029$; HF: $B=0.001, p=0.005$; HFnu: $B=0.0008, p<0.001$). Here, HRV was found to increase as days post injury increased (i.e. as the concussed athlete recovered). Significant main effects of post concussion symptom domains were also found across various HRV measures. Across all concussion symptom domains, increases in physical (pNN50, HF, HFnu), cognitive (pNN50, HF, HFnu), fatigue (pNN50, HF, HFnu) and emotional symptoms (HF, HFnu) were associated with increases in HRV (Table 3.3). Overall, these findings were in contrast with the hypothesis that increases in symptom reports would be associated with decreases in HRV. However, given that follow-up data collection time points involved clinical support and consultation, trends in HRV may have been influenced by the return-to-activity strategies offered within the study. No significant differences were found between concussed and control participants. Age, sex and history of concussion were accounted for in the mixed models but were removed due to their lack of significance and subsequent contribution to the model. These findings highlight the importance of corroborating a subjective measure (self-reported symptoms) with an objective measure (HRV) in the context of examining clinical and physiological recovery trajectories. Clinically, findings provide the foundation to understand the varied trajectory and relationship between objective physiological measures and subjective symptom reporting. This study acts as a first step in looking at the natural history of
concussion, while accounting for pre-injury HRV and the follow-up of youth athletes across multiple time points.

The final and third study of this thesis (Chapter 4) addressed objective 4: to explore the feasibility of a clinical intervention pilot study, examining the impact of a MBY intervention on physiological (HRV) and functional outcomes (self-efficacy and participation) in youth with persistent concussion symptoms. This pilot study utilized a case series design and included youth between the ages of 13 to 17 years old who were experiencing persistent concussion symptoms for greater than one month (N=6). The clinical intervention was an 8-week MBY intervention, carried out once a week, for 45 minutes.

Aligned with case series analysis, visualizations of change across pre-, post- and three months following intervention were used to investigate change within participants. While preliminary, trends towards increasing self-efficacy in academic, social and emotional domains were found following the intervention and maintained at the three-month follow-up. Trends of increasing HRV were also found following intervention and across the eight sessions of MBY. Finally, this intervention may have served as a catalyst for youth with persisting post-concussion symptoms to re-integrate pre-injury forms of physical activity as participants displayed increased amounts of moderate and vigorous physical activity following the intervention and maintained these levels of physical activity at 3 months. From a feasibility standpoint, this study demonstrated a replicable process for a larger-scale trial. Data collection time/methods as well as participant attendance and satisfaction were reflective of good clinical uptake for clients and health care providers. This pilot work is important in the context of a cost-constrained healthcare environment providing clinical interventions for youth who have experienced a concussion, and in particular, persistent post-concussion symptoms. Developing novel, feasible and group-based intervention protocols are crucial to: (1) addressing the needs of this complex population; and (2) developing service delivery models that focus on cost-effective specialized treatment. Future research with a larger sample and control group is warranted.

Lastly, Chapter 5 addressed objective 5 of this thesis: to propose a model of concussion management grounded in the values of occupational therapy and rehabilitation sciences, which reflects a more holistic account of the factors that contribute to recovery following youth concussion. To date, youth concussion and its subsequent recovery have been described as
heterogeneous: no one injury is the same; and, each youth is different in how he or she recovers. The Dove-Hawk Model introduced in this thesis provides a unique perspective that can be applied to the management of concussion within youth. This model considers factors not only related to the person, but the occupations the person performs and the environments in which they are performed. This model (1) provides insight on the differential spectrum of profiles that exist among youth who have experienced a concussion and (2) unpacks how these profiles can support client-centred rehabilitation. It is possible that specific rehabilitation approaches are more suitable based on how a youth approaches their own personal recovery. Here, if a youth has developed a fear response to re-integrating to previous occupations, an activation approach may be applicable to encourage symptom-limited participation. Conversely, if a youth displays high incentives to return to pre-injury occupation swiftly, a censoring approach may be applicable where education on safely and gradually returning to activity is warranted to mitigate risk of re-injury.

6.3 Contributions to the Field of Youth Concussion

International recommendations have suggested that return-to-play and return-to-learn following concussion involves physical and cognitive rest for 24-48 hours following the injury and symptom-limited activity thereafter, employing a gradual return to physical and cognitive exertion (McCrory et al., 2017). Progression from less demanding to more demanding physical and cognitive tasks has traditionally been determined by the absence of self-reported concussion symptoms (Davis et al., 2017; Haider et al., 2017; McCrory et al., 2017). However, this method places significant reliance on subjective report. Children and adolescents who are highly motivated to participate in sport and who do not want time away from sport activity may not be able to accurately gauge the potential long-term damage or the risk for more serious re-injury (Kroshus et al., 2014; Lovell et al., 2002). Studies have shown that despite self-reported concussion symptom resolution, altered brain function continues to persist in response to cognitive and physical stress (Fait, Swaine, Cantin, Leblond, & McFadyen, 2013; Johnson, Kegel, & Collins, 2011; Sinopoli et al., 2014). Thus, the trajectories of physiological and clinical recovery may not be parallel to one another. The exploration of both traditional subjective measures (symptom-reporting) and objective physiological measures (HRV) is well suited to fill a critical gap in the literature, especially within an understudied population. The contributions of this research are outlined in relation to the emerging trend of multi-modal assessment and the
shift towards exploratory clinical intervention. These themes will be linked to the BPS model, which was used to guide inquiry in this doctoral research.

6.3.1 Concurrent subjective and objective assessment

The assessment of concussion has been traditionally anchored in the evaluation and resolution of self-reported symptoms. However, there are barriers to this traditional model, which limits the research and clinical community’s ability to utilize more objective approaches to assess recovery. Firstly, if a youth is experiencing symptoms during an assessment following concussion and is unable to complete follow-up testing, the assessment is typically terminated with the inability to gauge how their performance was affected compared to baseline or compared to norms based on a particular measure (Reed et al., 2014). Secondly, a youth’s symptom score does not necessarily correlate to their ability to carry out daily activities. For example, a youth may report a reduction in their post-concussion symptoms but experience symptom exacerbation (e.g. mental fog, difficulty concentrating, fatigue) when returning to a full school day (Paniccia & Reed, 2017; Reed, 2011; Reed et al., 2014). Youth may be eager to return to previous occupations (e.g. school, sport) and the validity of their subjective report may be influenced by their motivation to swiftly return to activity (Paniccia & Reed, 2017). It may be that more objective measures can capture the sensitivities related to continued recovery, despite the clinical recovery of symptoms. Taken together, the exploration of a non-invasive, objective measure enables the safe assessment of recovery while the youth is symptomatic and a potentially more sensitive measure of recovery while the youth is asymptomatic.

Chapter 2 set the foundation of exploring a novel objective physiological measure by addressing the objective of: (1) describing natural variations in HRV in a healthy sample of youth athletes, when considering age, sex and concussion-like factors (symptom-reporting and concussion history). Drawing on the BPS model (Adler, 2009; Hatala, 2012), Chapter 2 explores psychosocial stressors that are experienced daily and manifest in the form of non-specific physical, cognitive, fatigue and emotional symptoms. These baseline, concussion-like symptoms were explored alongside an objective physiological mechanism such as HRV to examine if the magnitude of self-reported symptoms was associated with ANS perturbations. Further, key demographic variables were considered in this study where significant sex differences highlighted the variable ANS perturbations, experienced by males and females. This study was
the first step in understanding the relationship between subjective self-report symptoms and an objective measure, which supported the exploration of a novel physiological phenomenon from a multi-modal perspective.

Chapter 3 was an extension of Chapter 2’s findings and applied these findings to a concussed sample to explore the impact of concussive injury on youth athletes. Objectives 2 and 3 explored the effect of concussion on HRV in youth athletes across the recovery trajectory; and examined the relationship between traditional, subjective self-report (concussion symptom reporting domains) and objective HRV measures across days post injury in youth athletes, respectively. Aligned with the BPS model (Adler, 2009; Hatala, 2012), these objectives enabled a more dynamic understanding between the psychosocial stressors (e.g. youth sustaining a concussion, resulting in temporary removal from activity), physiological mechanisms (e.g. ANS perturbations assessed via HRV) and health outcomes (e.g. examining the trajectory of both self-report symptoms and HRV over days post injury). In Chapter 3, the variable of “time” provided the longitudinal context with which these factors were comprehensively explored. The findings from this study highlighted the potential difference in clinical versus physiological recovery. Within the visualizations depicted in Chapter 3 (Figure 3.1, 3.2, 3.3), the relationship between self-reported symptoms and HRV varies as a function of time. Acutely, HRV appears to decline even while symptoms resolve. One month following concussion, the trend then appears to reverse indicating an improvement in HRV while symptoms continue to abate. These differential trends across time, while preliminary, do make an important contribution to examining physiological mechanisms within youth athletes.

Across both healthy (Chapter 2) and concussed youth athletes (Chapter 3), a relationship between subjective symptoms and objective HRV was found. Thus, the presence of physiological perturbations appears to be present within a daily context, and in the form of concussion. However, it is unknown if the ANS responses following concussion are uniquely different from what would be expected from a “stressful life event”. It is not yet known if a similar stressful life event (e.g. prolonged flu) would elicit the same trajectories of clinical and physiological recovery seen in the concussed population. Further, it is important to note that no physiological thresholds have been established in the literature, which state that displaying a certain range of HRV necessarily means a perturbation above and beyond what would be
expected from the ANS. Nonetheless, the concurrent collection of subjective and objective data enables a holistic range of domains to be captured post concussion (Reed et al., 2014). The findings outlined in Chapters 2 and 3 provide the basis to further explore what measures, alone or in combination, are most sensitive to concussion amongst youth and can provide a more accurate index of post-concussion recovery. These chapters underscore the importance for future research to address the complexities of the relationship between subjective symptom reporting and an objective physiological measure (HRV). Section 6.4 will outline a proposed study.

6.3.2 Clinical intervention

The landscape of concussion treatment, in Canada specifically, has been summarized as: (1) inconsistent in the training and knowledge on traumatic brain injury, (2) often recommending unnecessary, costly and unsubstantiated treatment, and (3) lacking alignment with evidence-informed guidelines (Ellis et al., 2017). Within scarce public sector health care services available, management of persistent concussion is often constrained by limited clinical programs, limited appointments and a “consultative” approach (e.g. 1-2 sessions mainly focused on education, rather than traditional intervention approaches). There is a clear gap between the needs of the youth population following concussion and the current service delivery model in enabling return to meaningful activity.

Acute management of concussion amongst youth includes early identification, physical and cognitive rest in the first 24-48 hours (McCrorry et al., 2017), education and reassurance, with return to school accommodations occurring while the youth is still symptomatic (DeMatteo et al., 2015; Halstead et al., 2013; McGrath, 2010). Activity restrictions in the form of physical and cognitive rest have typically been prescribed as part of evidence-informed guidelines for youth who are experiencing concussion symptoms (McCrorry et al., 2013). However, the implementation of these guidelines are often challenging to interpret as the optimal amount of rest or safe amount of activity is still unknown (Hunt et al., 2016). Further, absolute rest is likely unrealistic for youth, in which youth will naturally transition back to an active lifestyle, especially those who are only mildly symptomatic (Schneider et al., 2013). While these aforementioned recommendations may be valuable in the acute phase (7-10 days), prolonged inactivity in the persistent phase (>1 month) may contribute to secondary challenges (Paniccia & Reed, 2017; Reed et al., 2015). From an impairment-focused point of view, these challenges can
include but are not limited to physical deconditioning, anxiety/stress, social isolation, depression, irritability, and ‘acting out’ behaviour at home and school (Kuehl, Snyder, Erickson, & McLeod, 2010; McCrory et al., 2017). Secondary challenges are also manifested in more functional domains of life such as reduced meaningful interactions with friends, teammates, teachers and coaches (Broshek, De Marco, & Freeman, 2015; Jonsson & Andersson, 2013).

A significant shift in clinical recommendations has occurred whereby prolonged rest and inactivity are discouraged and symptom-limited activity is encouraged to promote recovery (Grool et al., 2016; Imhoff, Fait, Carrier-Toutant, & Boulard, 2016; Reed et al., 2015). Aligned with the multifaceted BPS model, clinical interventions for youth concussion should: (1) combine an understanding of the biological aspects of mTBI and protect youth from risk of re-injury and (2) consider the psychosocial impacts that manifest as short-term (e.g. inability to concentrate in class) and long-term (e.g. prolonged absence from extracurricular activities) functional implications. Ultimately, youth with persistent symptoms experience limited occupational repertoires; they do not engage in the same number of occupations as prior to their concussion, have difficulty participating, or avoid re-integrating out of fear of symptom exacerbation (Paniccia & Reed, 2017). These challenges can impact self-efficacy, an individual’s perceived confidence in their abilities (Jonsson & Andersson, 2013). These findings underscore the importance of shifting from symptom-focused recovery to examining occupation-based factors such as self-efficacy and participation in meaningful activities.

Chapter 4 explored the feasibility and impact of MBY on physiological (HRV) and functional outcomes (self-efficacy and participation) in youth with persistent concussion symptoms. This chapter intentionally shifted away from the focus on self-report symptoms as an indicator of recovery and broadened the approach by examining functional measures that may be more ecologically valid, especially in a population that has experienced prolonged limitations in their ability to participation in meaningful occupation. This study was novel in its approach to incorporating a multitude of domains being explored in the literature; namely low-intensity physical activity, psychosocial distress tolerance, and re-labeling sensations and emotions within the present moment. Taken together, these domains addressed concurrently, are a promising area of clinical intervention. This chapter employs the BPS model (Adler, 2009; Hatala, 2012) as a guiding framework as it considered the physiological mechanisms at play within a chronic sample of youth athletes, psychosocial stressors captured by the lack of previously engaged
leisurely occupations, and *health outcomes* in examining both short-term and long-term effects of a holistic intervention.

### 6.4 Future Research Directions

The limitations and future directions for research are outlined within Chapters 2, 3 and 4. However, synergizing the suggestions for future study presented in these previous chapters to inform the design of a larger scale study grounded in the BPS model is needed. To summarize, the following limitations have been noted across this doctoral work:

- The samples of youth athletes included across the studies likely include variation in the frequency, intensity and duration of physical activity that they engage in (Tocci et al., 2017). Controlling for physical activity via actigraphy would enable a deeper understanding across healthy and concussed samples.

- The 24-hour recording protocol was open-ended in that youth were instructed to carry out their normal daily routines and it was unclear the time and quality of sleep they were receiving within this time frame. Sleep factors can significantly impact how an individual carries out their daily activities and can serve as a feedback loop to the ANS to regulate stress responses (Kim, Yoon, & Cho, 2014). Thus, a standardized assessment (i.e. sleep questionnaire) to quantify these sleep factors is needed.

- The small N in the control sample in Chapter 3 may limit the ability to draw conclusions when compared to the concussed sample. Further, the value of a “healthy” control group needs to be further explored, especially in the context of a physiological signal that was shown to vary across healthy, concussed and persistent concussion samples. Here, the exploration of 2 sub-groups (asymptomatic-healthy and symptomatic-healthy) within the control may disentangle this limitation.

- Mindfulness-based yoga appeared to show promise as a clinical intervention for youth with persistent concussion; expanding this study to a larger-scale trial with a control group is needed to investigate its efficacy more rigorously.

- The combination of subjective, physiological and functional outcomes is paramount in taking a multi-modal approach in assessment and intervention. Chapter 4 introduced the
concepts of self-efficacy, participation and physical activity repertoires. These measures are important in evaluating the internal and external validity of a future study.

The limitations noted above were outside the objectives of this thesis but nonetheless have significant value with respect to designing future research to further explore novel physiological phenomena within a pediatric population. Taken together, a future study exploring the effect of MBY in youth with concussion compared to controls is warranted. The objectives of this study would include: (1) exploring the effect of an 8-week MBY intervention on youth with concussion, compared to controls, (2) more specifically, explore the effect of MBY intervention across symptomatic concussed youth (group 1), asymptomatic concussed youth (group 2), and compared to symptomatic healthy youth (group 3) and asymptomatic healthy youth (group 4); (3) examine the impact of MBY on functional measures such as self-efficacy, participation, and concussion symptoms while considering extraneous variables such as physical activity and sleep quality; (4) examine potential change in ANS function pre-, post- and 3 months following MBY intervention; and (5) evaluate the relationship between physiological and functional outcomes across time, within a clinical intervention (MBY).

The proposed study is a multi-group pretest-posttest quasi-experimental design. Concussed participants will be included in the study if they have sustained a concussion and are between 1-3 months post injury, between the ages of 13 to 18 years old and English speaking. Exclusion criteria will include: neurological, developmental or severe psychiatric diagnoses, and cardiac disease. Upon screening these criteria, concussed participants will be divided intentionally into two groups: Group 1: concussed symptomatic, with a PCSI score > 3; Group 2: concussed asymptomatic, with a PCSI score <3. Inclusion criteria for control participants will include: 13-18 years old, and English speaking. Exclusion criteria will include: neurological, developmental or severe psychiatric diagnoses, cardiac disease and cannot have a history of concussion in the last 3 months. Upon screening these criteria, control participants will be divided intentionally into two groups: Group 1: healthy symptomatic, with a PCSI score > 3; Group 2: healthy asymptomatic, with a PCSI score <3. A variety of demographic, physiological and functional outcome measures will be collected along a repeated measures timeline: pretest, each week during the 8-week MBY intervention, posttest, and three months following the MBY intervention. Details on the study design and repeated measures timeline is presented in Figure 6.2. A detailed description of the measures can be found in Table 6.1.
Figure 6.2 Multi-group pretest-posttest quasi-experimental design protocol investigating the effects of MBY on concussed youth compared to controls, stratified by symptom status.

Table 6.1 Description of measures outlined in proposed MBY study.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographic Collection Form</strong></td>
<td>Age, sex, primary sport, concussion history</td>
</tr>
<tr>
<td><strong>Post-Concussion Symptom Inventory (PCSI)</strong></td>
<td>Severity of concussion symptoms across physical, cognitive, fatigue and emotional domains are rated on a scale from “0 – not a problem” to “6 – severe problem”. (Sady et al., 2014)</td>
</tr>
<tr>
<td><strong>Self-Efficacy Questionnaire – Children (SEQ-C)</strong></td>
<td>Self-efficacy rated on a scale from “1 – not at all” to “5 – very well” on a range of domains in daily life (e.g. academic, social and emotional). (Muris, 2001)</td>
</tr>
</tbody>
</table>
Leisurely occupations are captured with the following qualifiers: frequency, with whom, location and level of enjoyment. Activities cover those completed at home and within the community.

Heart Rate Variability (HRV)

Please see Chapters 2 and 3 for a comprehensive definition of this measure.

Actigraphy

Actiwatch used to collect frequency, intensity and duration of movement/activity; stratifies activity based on low, moderate and vigorous intensity.

Sleep and Concussion Questionnaire

Identifies and quantifies changes in sleep in response to concussion and brain injury and, monitors these changes over time.

The MBY intervention protocol will be similar to that conducted in Chapter 4 (Appendix 14; Appendix 17). Standard care will be offered in the form of one, 2-hour “Concussion and You” session based on the information provided in the “Concussion and You” handbook (Reed & Provvidenza, 2014). This tool has been deemed feasible within a concussed youth population (Hunt et al., 2016).

Preliminary data analysis within this study can include within and between group descriptive statistics, correlational analyses and a two-way ANOVA to examine how group status and time point result in changes in the measures outlined in Table 6.1. As this design is both multi-group and longitudinal, it will likely require a complex multi-level model approach to analysis, in which each participant is treated as his or her own unique trajectory (random intercept) and trends are aggregated across participants to yield fixed effects on outcomes of interest. Within this mode of analysis, controlling for factors such as physical activity (actigraphy), and sleep quality can be considered in the models. This multi-group design has the potential to disentangle the physiological effects of concussion as well as evaluating the efficacy of a novel clinical intervention. This study can begin to address the limitations that have been highlighted in concussion literature, as well as within this doctoral work.
6.5 Clinical and Research Relevance

The knowledge discovered within this thesis can be relevant and applicable to many stakeholder groups. Clinicians, researchers, youth and their families, as well as the youth sport community can benefit from both the strengths and limitations of this work. There is no gold standard in concussion treatment; rather multidisciplinary management of the injury (Ellis et al., 2017; Ellis, Leddy, & Willer, 2016) has been strongly recommended. Further, there has been recent interest in diagnostically stratifying concussion into streamlined mechanisms such as vestibular-ocular, physiological and cervicogenic causes (Ellis et al., 2016). This doctoral work did focus solely on the physiological mechanisms that are potentially at play, but the preliminary information acquired within a youth athlete sample does provide a foundation to build future pediatric studies on. The findings of this work do not conclusively result in the immediate clinical uptake of HRV, however, the principles of assessment beyond traditional self-report are important to consider. Clinicians who assess concussed youth can be prompted to take on a multi-modal approach to their assessment to ensure a youth’s recovery is captured with both subjective and objective measures. Clinicians also play a key role in implementing evidence-informed treatment. This thesis explored a novel intervention (MBY), which taped into creating linkages between physiological and functional outcomes. The intervention was observed to be feasible and experienced with a high level of satisfaction, important characteristics for future clinical study and in the eventual uptake of trialing this intervention within a rehabilitation or community setting.

The findings within this thesis are also relevant to researchers across the fields of mild traumatic brain injury, physiology, and pediatrics. The doctoral work presented directly addressed the gaps outlined by international consensus (McCrory et al., 2017) as well as a systematic review (Blake et al., 2016), which highlighted the lack of longitudinal and physiological studies in the pediatric population. Future studies can build on the foundation provided within this thesis and have a starting point to gain a greater understanding of the factors that play a role in ANS function within healthy and concussed youth athletes. From a methodology standpoint, this doctoral work offers a 24-hour recording protocol, different from the short-term, positional protocols utilized in concussion literature to date (Blake et al., 2016). The limitation to this novelty is that it is challenging to compare results across studies given the amount of variability in the physiological signal. However, the benefit of its novelty is that it introduces the potential for a more
ecologically valid approach to objectively measuring recovery, which is essential to return-to-activity decision-making. Here, the ability of a youth to adequately adapt to environmental change and demands is essential to their successful re-integration. Thus, assessing their abilities within a static physiological protocol may not be useful. Exploring the validity of this 24-hour protocol is in its early stages but warrants future study.

The youth sport community includes youth athletes, their families, coaches and trainers. Concussion has been conceptualized as an ‘invisible injury’, internally manifesting as a functional versus structural injury without positive neuroimaging findings (McCrory et al., 2017). Externally, there are no salient cues that would indicate that an individual has sustained a mTBI/concussion. Thus, within the sport community, the culture of “working through your pain or toughing it out” has been pervasive (Adler & Herring, 2011; Murray, Murray, & Robson, 2015). The exploration of objective measures may enable a deeper understanding that concussion is a brain injury, different from musculoskeletal injuries, and needs to be addressed in ways that promote optimal recovery and mitigate the risk for more serious secondary injury.

In sum, it is anticipated that the findings presented within this doctoral thesis can provide all the aforementioned stakeholders (e.g. clinicians, researchers and youth sport community) with new knowledge or a different approach to consider within the realm of assessment and intervention. Ultimately, it is hoped that outcome measurement for the purposes of determining recovery for youth following concussion can include the broad array of biological and psychosocial factors that are essential to returning to meaningful occupation.

6.6 Concluding Remarks

Management of concussion, especially within the pediatric population, has been a long-standing challenge to both clinical and research communities. This is problematic as early return to activity may result in a protracted recovery (McCrory et al., 2017) and a decreased ability to process and respond to complex environments (Fait et al., 2012). Using HRV as a neurophysiological parameter expands on current measures by including an objective indicator of stress capacity and ANS function. The chapters presented within this thesis utilized HRV as an objective measure alongside the self-reported symptoms of youth athletes. An apparent relationship was found between subjective self-reported symptoms and objective HRV across healthy, concussed and persistent concussion samples. The overall aim of this research was to
enhance knowledge on the potential physiological mechanisms of concussion in an understudied population within a more objective context. Further, linkages between physiological and functional outcomes were important to make within a pilot and feasibility study, examining the impact of MBY on youth who were slow to recover from concussion. Across an array of research fields, it is hoped that the knowledge acquired from this thesis can serve as a first step to more rigorous and controlled longitudinal studies with children and youth making up the study sample. Regarding front-line health care professionals and clinicians, the principles of considering objective measures and functionally driven intervention are key to consider for practicing within the scope of being a scholarly healthcare professional. Lastly, for the youth athlete population at large, this thesis may provide new knowledge to help shift the culture of sport concussion and provide new ways to conceptualize recovery. Ultimately, this research provided the framework to demonstrate that novel physiological phenomena should be considered within a multi-faceted and dynamic context (i.e. clinical assessment and functional intervention) – one that considers both the biological and psychosocial factors that contribute to recovery from a concussive injury.
6.7 References


Appendices

Appendix 1

Consent Form

Information Letter and Consent Forms for Participation in:

‘NeuroCare’ as Innovation in Intervention: A neurophysiological approach to determine readiness for return to activity

Dear youth,

My name is Michelle Keightley. I am part of a research team at the Holland Bloorview Kids Rehabilitation Hospital that is studying Sports-Related Concussion in Children and Youth. Before agreeing to take part in this study, it is important that you understand how you will be involved.

What is the study about?

We want to learn more about recovery from sports-related concussion in children and youth. Specifically, we want to know how youth athletes feel after a concussion. Things like headaches, feeling sick to their stomach or feeling more tired than normal. We want to know if these feelings affect performance on brain and body fitness tests. This information can help create return-to-activity (school, sport etc.) guidelines specific to youth athletes.

We also want to learn more about whether the brain and body are ready to increase activity after a concussion by measuring heart rate. We will use this new approach alongside other measures of concussion recovery. These include measures of symptoms, balance, thinking, strength, and brain function. We will use a special camera to let us see how the brain works. We hope that this new approach can tell us more about when young athletes are ready to return to activity after a concussion. We are not sure this new approach works. That is why we are doing this study.

What will happen during the study?

We will ask you to take part in up to 2 different parts

A. Brain and Body Fitness Testing and Long Duration Heart Rate Monitoring

B. Functional Magnetic Resonance Imaging (MRI) of the Brain

We would like to invite you to participate in the first part of this study. If you are contacted again to participate in part 2 of our study (MRI), we will ask for your permission again. We will ask for your email when you come for the testing in case we need to contact you again. We want to learn more about how youth athletes recover after a concussion. In order to participate you must show me that you understand what you will have to do in this study and what the risks and benefits to being in the study are. If you can not do this, then you cannot take part in the study. A researcher will also meet with you to review everything in this letter. You can decide then if you want to take part.
How many people will participate in this study?

There will be different numbers of participants completing the different aspects of this study. Male and female athletes between the ages of 10-18 years have been invited to take part in this study.

A. Brain and Body Fitness Testing/ Long Duration Heart Rate Monitoring: Up to 1400 athletes will take part in this study. A member of the research team within the BrainFit Lab at Holland Bloorview Kids Rehabilitation Hospital (150 Kilgour Rd., Toronto) will complete brain and body fitness tests with you. These tests will take approximately 1-2 hours to complete. These tests will measure your brain health, cognitive/thinking performance, balance performance, strength performance and heart rate. When you come in for testing, we will ask for your email address just in case we have to contact you again.

• These tests will be completed at baseline (or at the start of the sport/school year before an injury happens).
• You will be asked to wear a heart rate monitor for 24 consecutive hours. The heart rate monitor involves wearing a watch and a chest strap. The monitor does not hurt and all testing takes place on the outside of the body. While wearing the heart rate monitor you may do all the things you normally do in a day including while you sleep. However, activities that might get the monitor wet (swimming, bathing etc.) cannot be done.
• Heart rate monitoring will involve athletes who get and do not get injuries. You will complete an activity log to track what you do during the 24 hours that you wear the heart rate monitor. This activity log will take approximately 5 minutes to complete. We will show you how to fill in this log.

If you experience a concussion during your sport season, you will do these same tests again immediately following injury (within 48 hours). Each time we will take 1-2 hours at Holland Bloorview. You will also do the same tests weekly until post-concussion symptoms have gone away. Then you will do the tests 4 more times: 1-week, 1 month, 3 months and 6 months after post-concussion symptoms have gone away.

• If you experience a concussion during your sport season, we may ask that you bring a friend (who has not recently had a concussion) and who is the same age and gender as you to participate in the same brain and body tests that you do following your injury. You will get an information sheet to give to your friend and they can decide then if they want to participate.
• If you get an orthopaedic injury (e.g., broken arm, sprained ankle etc.), instead you may be invited to do these same tests again immediately following the injury (within 48 hours). You will do the same number of tests as the athletes who get a concussion. It will also take 1-2 hours at Holland Bloorview.
• If you get both a concussion and an orthopedic injury, you can only be in one follow-up group.
• Remember it is possible that your ability to return to competitive sports will be delayed after a concussion; but this will only happen if you don’t feel well enough to play, not because you are participating in this study.
Even if you don’t get a concussion or orthopedic injury, we may contact you to do these other tests. We will only contact you if you match the age and sex of another participant who has a concussion. You can decide then if you want to do them.

- Brain and body fitness testing will also include recording your history of concussions and other history of medical conditions you may have had. Also, we will be collecting information on age, height, weight, sport(s) played, playing position and level of play. This information will be used to find out if some participant characteristics are more related to performance on brain and body fitness tests than others. Collecting this information will take approximately 10 minutes.

If you have questions concerning the Brain and Body Fitness Testing portion of this study, please call Michelle at 416.425.6220 ext 6651 or Nick at 416-425-6220 x3861.

B. Functional Magnetic Resonance Imaging of the Brain: Up to 75 athletes who did the brain and body fitness testing will do this part of the study. A member of the research team at the Toronto Western Hospital (399 Bathurst St., Toronto) will complete brain imaging with you using a MRI machine. This testing will take approximately 1½ hours to complete. The MRI machine is a powerful magnet that looks like a big doughnut, and you will lie down on a bed with your head and shoulders in the “doughnut hole”. We will put some pillows around your head to keep it from moving and then ask you to stay very still while we scan your brain to get the pictures. Some of the brain scans will take pictures of the brain’s structure and some others will take pictures of the brain’s activity. During the brain activity scans, you will be asked to perform a computer task. This computer task will ask you to press a button in response to pictures and words that you see. You will see a series of pictures or words. You will then see a second series of pictures or words. During this second series of pictures or words, you will be asked to press one button if you saw the picture or word in the first series and another button if you did not see the picture or word in the first series.

- If you experience a concussion during your sport season, you will be asked to complete two brain scans. The first will be completed within 48-72 hours of the concussion and the second will be completed within 1 week after concussion symptoms have resolved.
- If you experience an orthopaedic injury (e.g., broken arm, sprained ankle etc.), you may be asked to complete two brain scans after your injury. The first will be completed within 48-72 hours of the concussion (experienced by another participant in the study) and the second will be completed within 1 week after their concussion symptoms have resolved.

Additionally, we will have an equal number of athletes who have not been injured (no concussion or orthopaedic injury) complete the same number of brain scans. If this is you, you will only be invited to do the MRI scan if you match another athlete that is the same age and sex as you.

If you have questions concerning the Functional Magnetic Resonance Imaging of the Brain portion of this study, can call Karen Davis at 416.603.5662.

Are there any risks to doing the study?

A. Brain and Body Fitness Testing/Long-Duration Heart Rate Monitoring: There is the possibility that some of the testing and questions may be fatiguing, stressful or produce unpleasant feelings.
You will be able to stop or take a break at any time if you feel too uncomfortable. You do not need to answer questions that you do not want to answer or that make you feel uncomfortable. We will tell you what questions need to be answered or tests that need to be done to stay in the study.

There are no known risks with long duration heart rate monitoring. You may experience some discomfort and frustration while wearing the heart rate monitor for the 24 hour period. At any time, you can stop doing this part. You can remove the monitor at any time and no one will mind.

C. Long Duration Heart Rate Monitoring: There are no known risks with long duration heart rate monitoring. You may experience some discomfort and frustration while wearing the heart rate monitor for the 24 hour period. At any time, you can stop doing this part. You can remove the monitor at any time and no one will mind.

Are there any benefits to doing this study?

We hope to better understand recovery in young athletes following concussion. This study could help other children and youth like you who have experienced concussions in the future.

Payment or Reimbursement

Some aspects of this study will include reimbursement for participation:

A. Brain and Body Fitness Testing/Long-Duration Heart Rate Monitoring:

You will be given a $10 gift card from Tim Horton’s for wearing the heart rate monitor for the 24 hour period. If the testing session is not completed for any reason, and you drop out during the testing session, you will still receive the gift card.

Control participants (no injury or orthopaedic injury) who complete additional brain and body fitness testing (in addition to baseline/pre-injury testing) will be reimbursed $40 per additional testing session. If the testing session is not completed for any reason, you will still receive the full reimbursement.

B. Functional Magnetic Resonance Imaging of the Brain:

You will be given a $40 gift card from SportChek per brain imaging session. If the testing session is not completed for any reason, you will still receive the gift card.

Will anyone know what you say?

All the information we collect about you will be kept private. Rather than use your name on study papers, a randomly assigned identification number will be used. No one but the study staff will know that it was you who was in the study.

We will not make public anything that might identify you, unless required by law. For example, we have a legal duty to report suspected child abuse and potential harm to self or others. If the results of the study are published, your name will not be used. All data collected will be combined to form one large data set. As a result, individual sport teams and participants will not
be identified. We must keep the research data we collect for 7 years as required by Holland Bloorview.

We will keep all of your information in a locked cabinet the BrainFit lab. Only the researchers who are directly involved in this study will have access to your information. All of your information that is kept on the computers in the lab will be protected by a special password that only the researchers know.

Because we are asking your whole team to participate, there is a chance that your teammates might know that you are participating in this study. They also might know if you get a concussion or an orthopaedic injury.

You do not give up legal rights due to research-related harm.

There is a possibility that our findings will be commercialized and you will have no ownership rights over the information. It is possible that a company or Holland Bloorview may get money from the sale of certain products in the future.

**Do I have to do this?**

If you decide not to take part in this study, that is okay. If you decide to take part, but then at any time during the study you no longer want to participate, that is okay. This will not affect your involvement with your sport team or your treatment at Holland Bloorview Kids Rehabilitation Hospital.

**What if I have questions?**

Please ask me to explain anything you don’t understand before signing the consent forms. My phone number is 416.425.6220 ext 6651 or Nick Reed (researcher at Holland Bloorview) at 416.425.6220 ext 3861. If you leave a message, I or a member of the research team, will return your call within 48 hours.

If you have any questions about your rights as a research participant, please contact the Holland Bloorview Research Ethics Board at 416-425-6220 ext. 3507.

Thank you for thinking about helping us with this project.

Yours truly,

Michelle Keightley, Ph.D., C.Psych.
Clinician Scientist
BrainFit Lab, Bloorview Research Institute
150 Kilgour Rd., Toronto, ON, M4G 1R8
mkeightley@hollandbloorview.ca
416.425.6220 ext 6651
CONSENT FORM #1

BLOORVIEW RESEARCH INSTITUTE

‘NeuroCare’ as Innovation in Intervention: A neurophysiological approach to determine readiness for return to activity

RE: Participating in the ‘Brain and Body Fitness Testing and Long Duration Heart Rate Monitoring’ portion of this study

Please complete this form below and after discussing it with your family, please return it to the researcher. You will receive a signed copy of this form.

________________________ explained this study to me. I have read the attached Information Letter and understand what this study is about.

I understand that I may drop out of the study at any time.

I agree to participate.

_________________________  _________________________  _____________
Youth’s Name (please print)  Signature               Date

I support my child’s decision to take part in this research study.

_________________________  _________________________  _____________
Parent’s Name (please print)  Signature               Date

I have explained this study to the above participant and have answered all their questions.

_________________________  _________________________  _____________
Name of Person Obtaining Consent  Signature               Date
Appendix 2

Participant Recruitment Letter

Research Participants Needed

‘NeuroCare:’ Determining readiness for return to activity after youth concussion

A concussion, also known as mild Traumatic Brain Injury (mTBI for short), is a common form of head and brain injury, and can be caused by a direct or indirect hit to the head or body (for example, a car crash, fall or sport injury). This hit to the head causes a change in brain function, which results in a variety of symptoms. To learn more about concussions, visit Think First Canada at www.thinkfirst.ca or the BrainFit Lab at www.brainfitlab.com.

To help youth athletes with concussion, we are looking to determine how the youth brain and body recover after a concussion and if there are improved ways that we can measure if young people are ready to return to activity (sport, school etc.) Through this research, we hope to change the way we manage concussion in youth athletes and to improve the lives of children across the world.

We want to learn more about recovery from sports-related concussion in children and youth. Specifically, we want to know how youth athletes feel after a concussion. Things like headaches, feeling sick to their stomach or feeling more tired than normal. We want to know if these feelings affect performance on brain and body fitness tests. This information can help create return-to-activity (school, sport etc.) guidelines specific to youth athletes.
We also want to learn more about a new approach using heart rate as a way of knowing if the brain is ready to take on more activity after a concussion. We will compare this new approach to other approaches more commonly used in the past (balance, thinking, strength, brain scanning/imaging). We hope that this new approach will let us know if young athletes like you are ready to return to activity after a concussion.

All participants will complete a 1-2 hour baseline (or pre-injury) assessment of thinking ability, balance, strength and heart rate at the start of their sport season. Athletes who get a concussion during their sport season will do the same assessment after the injury at different times so we can track changes in performance and recovery (immediately following the injury, weekly until post-concussion symptoms have gone away, as well as 1-week, 1 month, 3 months and 6 months after post-concussion symptoms have gone away). This testing will match up with rehabilitation services and care provided at the Holland Bloorview Kids Rehabilitation Hospital within the BrainFit Lab. Some participants will also take part in other parts of the study looking at brain imaging and heart rate monitoring.

Some athletes who have orthopedic injuries (sprained ankle, broken arm etc.) and who do not have any injury during their sport season will also complete the same testing. This will let us compare concussed and non-concussed athletes.

You do not have to pay anything to take part in this research project.

We are looking for male and female athletes between the ages of 10 to 18 years who participate in competitive sports that have a high risk for concussion (hockey, lacrosse, football, rugby, soccer, cheerleading). You cannot take part in the study if: 1) You cannot read or understand English; 2) you cannot understand the study and show you can consent on your own to participate in it (e.g. cannot answer any questions about what you will be doing in the study); 3) you have a prior history of a neurological or cardiovascular condition; 3) you have a prior history of a psychiatric disease or mental health condition; 4) you are currently taking medication that may influence heart rate or blood pressure. You can still participate in this study if you have had a concussion before.
This study will be conducted by Dr. Nick Reed at the Holland Bloorview Kids Rehabilitation Hospital. Nick is a Clinician Scientist and Occupational Therapist at the hospital. Nick and his clinical team specialize in providing care to young athletes following concussion and researching improved ways of evaluating recovery after this injury.

If you are interested in participating, please contact or Nick Reed (nreed@hollandbloorview.ca).

I have attached a consent form that talks about the study in further detail for your reference.

Thank you for thinking about being involved!
Appendix 3

Demographic Collection Form

Test Station 1: (Demographic Form, HRV, PCSI)

Demographic Information Form

Data Collection Form

REB Number ______  Participant ID Number ________________

Participant Characteristics

Gender: ________

Height: _____ft _____in

Weight: _______ lbs.

Body Mass Index (BMI): ________

Date of Birth: Month:_____Year:_____ Age: _________

Contact Person: ____________________________________

Email: ____________________________________________

Academic history:

Year of education completed (including kindergarten): ______

Received Speech Therapy:  □ no  □ yes  □ Unknown

Attended Special Education:  □ no  □ yes  □ Unknown

Repeated year(s) in school:  □ no  □ yes  □ Unknown

Diagnosed with a learning disability:  □ no  □ yes  □ Unknown

Problems with ADD/hyperactivity:  □ no  □ yes  □ Unknown
Concussion history:

☐ no  ☐ yes

Number of previous concussions: ________________________

Date(s) of last concussion(s): __________________________

Symptom duration: ____________________________________

Total games missed due to concussions combined: ______

General medical history (any additional medical issues):

____________________________________________________________________________________

____________________________________________________________________________________

____________________________________________________________________________________

____________________________________________________________________________________

____________________________________________________________________________________

Present medication:

____________________________________________________________________________________

____________________________________________________________________________________

____________________________________________________________________________________

____________________________________________________________________________________

<table>
<thead>
<tr>
<th>Sports Played</th>
<th>Level of Play</th>
<th>Position</th>
<th>Times per Week</th>
<th>Years Played</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Previous physical activity within the past 4 hours:

____________________________________________________________________________________
Appendix 4

Post-Concussion Symptom Inventory

Post-Concussion Symptom Inventory (PCS1)
Self-Report Assessment Form
Pre and Post-Injury Report
Ages 13-18

Patient Name: ____________________________  Today's date: ___________
Birthdate: ____________  Age: __________

Instructions: We would like to know if you have had any of these symptoms before your injury. Next, we would like to know if these symptoms have changed after your injury. Please rate the symptom at two points in time - Before the Injury/Pre-Injury and Currently.

Please answer all the items the best that you can. Do not skip any items. Circle the number to tell us how much of a problem this symptom has been for you.

0 = Not a problem  3 = Moderate problem  6 = Severe problem

<table>
<thead>
<tr>
<th>No.</th>
<th>Symptom</th>
<th>Before the Injury/ Pre-Injury</th>
<th>Current Symptoms/ Yesterday and Today</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Headache</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>2</td>
<td>Nausea</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>3</td>
<td>Balance problems</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>4</td>
<td>Dizziness</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>5</td>
<td>Fatigue</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>6</td>
<td>Sleep more than usual</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>7</td>
<td>Drowsiness</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>8</td>
<td>Sensitivity to light</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>9</td>
<td>Sensitivity to noise</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>10</td>
<td>Irritability</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>11</td>
<td>Sadness</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>12</td>
<td>Nervousness</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>13</td>
<td>Feeling more emotional</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>14</td>
<td>Feeling slowed down</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>15</td>
<td>Feeling mentally “foggy”</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>16</td>
<td>Difficulty concentrating</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>17</td>
<td>Difficulty remembering</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>18</td>
<td>Visual problems (double vision, blurring)</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>19</td>
<td>Get confused with directions or tasks</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>20</td>
<td>Move in a clumsy manner</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>21</td>
<td>Answer questions more slowly than usual</td>
<td>0 1 2 3 4 5 6</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>22</td>
<td>In general, to what degree do you feel “differently” than before the injury (not feeling like yourself)?</td>
<td>No Difference 0 1 2 3 4 Major Difference</td>
<td></td>
</tr>
</tbody>
</table>

Circle your rating with “0” indicating “Normal” (No Difference) and “4” indicating “Very Different” (Major Difference)
Appendix 5

Polar Technology Specifications

Technical Specifications

### Training computer

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery life</td>
<td>Average 1 year (1h/day, 7 days/week)</td>
</tr>
<tr>
<td>Battery type</td>
<td>CR2032</td>
</tr>
<tr>
<td>Battery sealing ring</td>
<td>0-Ring 20.0 x 1.1, material silicone</td>
</tr>
<tr>
<td>Wrist band and buckle material</td>
<td>Polyurethane, stainless steel</td>
</tr>
<tr>
<td>Back cover</td>
<td>Polyamide, stainless steel complying with the EU Directive 94/27/EU and its amendment 1993/EC 205/02 on the release of nickel from products intended to come into direct and prolonged contact with the skin.</td>
</tr>
<tr>
<td>Watch accuracy</td>
<td>Better than ± 0.5 seconds /day at 25 °C / 77 °F temperature.</td>
</tr>
<tr>
<td>Heart rate measuring range</td>
<td>± 1% or 1 bpm, whichever larger. Definition applies to stable conditions.</td>
</tr>
<tr>
<td>Current speed display range</td>
<td>Stride sensor: 0-36 km/h or 0-22,3 mph, cadence 0-255 rpm</td>
</tr>
<tr>
<td></td>
<td>Speed sensor: 0-127 km/h or 0-78.9 mph</td>
</tr>
<tr>
<td>Cadence sensor</td>
<td>Cadence sensor: 15-200 rpm</td>
</tr>
<tr>
<td>Altitude display range</td>
<td>-550 m ... +9000 m / -1800 ft ... +29500 ft</td>
</tr>
<tr>
<td>Ascent/Descent resolution</td>
<td>The Polar wrist unit calculates altitude by using the standard average altitude at defined air pressures according to ISO 2533.</td>
</tr>
<tr>
<td></td>
<td>5 m / 20 ft</td>
</tr>
</tbody>
</table>

### Training computer limit values

<table>
<thead>
<tr>
<th>Limit value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum files</td>
<td>99</td>
</tr>
<tr>
<td>Maximum time</td>
<td>99 h 59 min 59 s</td>
</tr>
<tr>
<td>Maximum manual laps</td>
<td>99</td>
</tr>
<tr>
<td>Maximum automatic laps</td>
<td>99</td>
</tr>
<tr>
<td>Shoes 1/2/3 total distance</td>
<td>999 999 km / 621370 mi</td>
</tr>
<tr>
<td>Bike 1/2/3 total distance</td>
<td>999 999 km / 621370 mi</td>
</tr>
<tr>
<td>Total Shoes / Total GPS / Total Bikes distance</td>
<td>999 999 km / 621370 mi</td>
</tr>
</tbody>
</table>

### Heart rate sensor

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery life</td>
<td>1600 h</td>
</tr>
<tr>
<td>Battery type</td>
<td>CR2025</td>
</tr>
<tr>
<td>Battery sealing ring</td>
<td>0-ring 20.0 x 0.90 Material Silicone</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-10 °C to +40 °C / -14 °F to 104 °F</td>
</tr>
<tr>
<td>Connector material</td>
<td>Polyamide</td>
</tr>
<tr>
<td>Strap material</td>
<td>38% Polyamide, 29% Polyurethane, 20% Elastane, 13% Polyester</td>
</tr>
</tbody>
</table>

### Polar ProTrainer 5™

#### System Requirements:

PC
Windows® 2000/XP (32bit), Vista
IrDA compatible port (an external IrDA device or an internal IR port)
Additionally, for the software your PC must have a Pentium II 200 MHz processor or faster, SVGA or higher resolution monitor, 50 MB hard disk space and a CD-ROM drive.

### Polar WebLink using IrDA Communication

#### System Requirements:

PC
Windows® 2000/XP, Vista 32/64-bit or Windows 7 32/64-bit
IrDA compatible port (an external IrDA device or an internal IR port)
These technical specifications have been taken from the RS800CX user manual, which can be retrieved from:
https://support.polar.com/e_manuals/RS800CX/Polar_RS800CX_user_manual_English/manual.pdf
Appendix 6
Heart Rate Monitor Participant Instruction Sheet

24-Hour Activity Log

<table>
<thead>
<tr>
<th>Time</th>
<th>Event/Activity</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sleep Time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wake-up Time</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Attaching heart rate sensor and chest strap

1) Attach the connector sensor onto the strap and push until you hear 2 clicks (Be sure the “Polar” symbol is upright when you attached the strap around the body with the clip on the left side)
2) Squeeze a very light line of gel onto the back of the chest strap only on the plastic part (not on the fabric)
3) Attach the chest strap around the body just below the chest muscles
4) Adjust the strap so that it feels tight but comfortable and wont slide around.

Turning ON the watch to begin recording

1) Press the red button near the bottom of the watch and wait to see your heart rate appear near the bottom of the screen.
2) Once the heart rate is shown then press the red button again to begin recording
3) The watch should now display the running time and the heart rate at the bottom of the screen
4) Keep the watch running for 24 hours

Turning off the watch and packing up

1) When the 24 hour period is completed turn off the watch recoding by pressing the “stop” button in the bottom left corner of the watch
2) Select “stop recording” by pressing the bottom left button a second time
3) To confirm that the recording has stopped the display should show the current time of day
4) Take off the chest strap and detach the connector sensor from the chest strap (some force may be required)
5) Fold the chest strap gently and place in the box with the gel, sensor connecter and watch.
6) Be sure the 24 hour log is filled out properly and instruction manual is included

You can shower but not bath or swim with this heart rate monitor on.
Appendix 7
RHRV Script

###HRV Program

library(RHRV)

library(lubridate)

###Enter window size and shift

options("digits secs"=5)

subjectID <- 1

window.size <- 300

window.shift <- 300

#####List .hrm files in directory

file.check <- list.files("D:/HRV/Data", pattern = "\.hrm\$", ignore.case = TRUE, full.names = TRUE)

file.check.length<-length(file.check)

files<-vector()

short.file<-vector()

for (j in 1:file.check.length){

  file.scan <- file.check[j]

  ######Get starttime and date

  check <- scan(file.scan, skip=6,nmax=1, what=list(""))

  time<-hms(substr(check[[1]],8,17))

  time.min<-hms("00:07:00")
if (time>time.min) {files[length(files)+1]<-file.check[j]} else {short.file[length(short.file)+1]<-file.check[j]}

} write.table(files, "D:/HRV/Data/Filesanalyzed.txt", sep="\t", row.names=FALSE)
write.table(short.file, "D:/HRV/Data/notanalyzed.txt", sep="\t", row.names=FALSE)
HRVout<-read.table("D:\HRV\Data\HRVVariables.txt",header=T)
num.files<-length(files)
for (i in 1:num.files) {
    file.name <- files[i]
    file.name
    ######Get starttime and date
    x <- scan(file.name, skip=4,nmax=2, what=list(""))
    x.frame<-as.data.frame(x)
    date<-ymd(substr(x.frame[1,],6,14))
    date<-format(date, "%d/%m/%Y")
    starttime<-substr(x.frame[2,],11,20)
    DateTime <- paste(date, starttime)
    date1<-dmy_hms(DateTime)
    ######input RR
    RR.input<-scan(file.name, what=list(name=""))
    start.read<-which(RR.input$name=="[HRData]")
x<-start.read + 1

y<-length(RR.input$name)

RR.input<-as.numeric(RR.input$name[x:y])

Length.Rec<-sum(RR.input)/1000

###RR<-as.data.frame(RR.input)

write(RR.input,file="D:/HRV/Data/testing.txt",ncolumns=1)

###New HRV Data list

hrv.data = CreateHRVData()

hrv.data = SetVerbose(hrv.data, TRUE )

hrv.data<-LoadBeatRR(hrv.data, "testing.txt", RecordPath="D:/HRV/Data", scale = 0.001, datetime = DateTime)

hrv.data = BuildNIHR(hrv.data)

hrv.data = FilterNIHR(hrv.data)

hrv.data = InterpolateNIHR (hrv.data, freqhr = 4)

hrv.data = SetVerbose(hrv.data,FALSE)

hrv.data = CreateTimeAnalysis(hrv.data, size = window.size,interval = 7.8125)

hrv.data = CreateFreqAnalysis(hrv.data)

hrv.data = CalculatePowerBand( hrv.data , indexFreqAnalysis= 1, size = window.size, shift = window.shift, type = "fourier", ULFmin = 0, ULFmax = 0.003, VLFmin = 0.003, VLFmax = 0.04, LFmin = 0.04, LFmax = 0.15, HFmin = 0.15, HFmax = 0.4 )
```r
# Plot Power Band (hrv.data, indexFreqAnalysis = 1, ymax = 5000, ymaxratio = 10, hr=TRUE, normalized=TRUE)

fgh <- hrv.data["Beat"]

fgh <- as.data.frame(fgh)

names(fgh)

fgh$Time[1]

fgh$Time <- as.duration(fgh$Time)

fgh$Time <- fgh$Time + date1

#par(mfrow = c(5, 1))

#plot(fgh$Time, fgh$RR, type="l", ylab="R-R interval(s)", xlab="Time of Day")

#plot(fgh$Time, fgh$niHR, type="l", ylab="niHR (bpm)", xlab="Time of Day")

abc <- hrv.data[["FreqAnalysis"]]

HRVTotal <- abc[[1]]$ULF + abc[[1]]$VLF + abc[[1]]$LF + abc[[1]]$HF

HRVLF <- abc[[1]]$LF

HRVHF <- abc[[1]]$HF

HRVLFHF <- abc[[1]]$LFHF

HRVHFLF <- abc[[1]]$HF / abc[[1]]$LF

meanHF <- mean(HRVHF)

meanLF <- mean(HRVLF)
```
meanLFHF<- mean(HRVLFHF)
meanHFLF<- mean(HRVHFLF)
meanTotal<- mean(HRVTotal)

HFnu<- meanHF/(meanTotal-mean(abc[[1]]$ULF)-mean(abc[[1]]$VLF))*100
LFnu<- meanLF/(meanTotal-mean(abc[[1]]$ULF)-mean(abc[[1]]$VLF))*100

### Set time vector

start.time.FFT<-window.size/2
end.time.FFT<-start.time.FFT+(length(HRVTotal)-1)*window.size
FFT.length<-seq(start.time.FFT, end.time.FFT, window.shift)
FFT.time<-as.duration(FFT.length)+date1

#plot(FFT.time,HRVTotal, type="l",xlim=c(min(fgh$Time),max(fgh$Time)),
    # ylab="Total HRV", xlab="Time of Day")
#plot(FFT.time,HRVLF, type="l",xlim=c(min(fgh$Time),max(fgh$Time)),
    # ylab="LF HRV", xlab="Time of Day")
#plot(FFT.time,HRVHF, type="l",xlim=c(min(fgh$Time),max(fgh$Time)),
    # ylab="HF HRV", xlab="Time of Day")

#### Find highest Total HRV period

max.line <- which.max(HRVTotal)
max.HRVTotal.time <- ymd_hms(FFT.time[max.line])
max.HRVTotal <- HRVTotal[max.line]
max.HRVLF <- HRVLF[max.line]
max.HRVHF<- HRVHF[max.line]

####Find highest LF period
max.line.LF <- which.max(HRVLF)
max.HRVLF.time <- ymd_hms(FFT.time[max.line.LF])
max.HRVLF.only <- HRVLF[max.line.LF]

####Find highest HF period
max.line.HF <- which.max(HRVHF)
max.HRVHF.time <- ymd_hms(FFT.time[max.line.HF])
max.HRVHF.only <- HRVHF[max.line.HF]

#max.HRVTotal.time
#max.HRVTotal
#max.HRVLF
#max.HRVHF
#max.HRVLF.time
#max.HRVLF.only
#max.HRVHF.time
#max.HRVHF.only

#####Save Data
### TimeAnalysis

```r
out <- (list(substr(file.name, 13, 20),

Length.Rec, 0, 60000/mean(gh$RR),

hrv.data$TimeAnalysis[[1]]$SDNN,

hrv.data$TimeAnalysis[[1]]$SDNNIDX,

hrv.data$TimeAnalysis[[1]]$SDANN,

hrv.data$TimeAnalysis[[1]]$rMSSD,

hrv.data$TimeAnalysis[[1]]$pNN50,

meanHF, meanLF, meanLFHF, meanHFHF, meanTotal,

HFnu, LFnu,

mean(hrv.data$TimeAnalysis[[1]]$HRVi),

max.HRVTotal,

max.HRVTotal.time,

max.HRVLF,

max.HRVHF,

max.HRVLF.only,

max.HRVLF.time,

max.HRVHF.only,

max.HRVHF.time))

HRVout <- rbind(HRVout, out)
```

HRVout

### Output and Save Data
HRVoutdata<-HRVout

#####to get back to date use: as.POSIXct(as.numeric(out[25]),
origin="1970-01-01", tz="UTC")

write.table(HRVoutdata, "D:/HRV/Data/HRVdata.txt", sep="\t",
row.names=FALSE)
**Appendix 8**

**Acute Concussion Evaluation Form**

**ACUTE CONCUSSION EVALUATION (ACE)  
Physician/Clinician Office Version**

Gerard Gioia, PhD & Micky Collins, PhD  
Children’s National Medical Center

---

### A. Injury Characteristics

<table>
<thead>
<tr>
<th>Date/Time of Injury</th>
<th>__ Patient __ Parent __ Spouse __ Other __</th>
<th>Reporter: __ Patient __ Parent __ Spouse __ Other __</th>
</tr>
</thead>
</table>

1. **Injury Description**

1a. Is there evidence of a forcible blow to the head (direct or indirect)? __ Yes __ No __ Unknown

1b. Is there evidence of intracranial injury or skull fracture? __ Yes __ No __ Unknown

1c. Location of Impact: __ Frontal __ Lt Temporal __ Rt Temporal __ Lt Parietal __ Rt Parietal __ Occipital __ Neck __ Indirect Force

2. **Cause:** __ MVC __ Pedestrian-MVC __ Fall __ Assault __ Sports (recreational) __ Other __

3. **Amnesia Before (Retrograde):** Are there any events just BEFORE the injury that you/your person has no memory of (even brief)? __ Yes __ No __ Duration __

4. **Amnesia After (Anterograde):** Are there any events just AFTER the injury that you/your person has no memory of (even brief)? __ Yes __ No __ Duration __

5. **Loss of Consciousness:** Did you/your person lose consciousness? __ Yes __ No __ Duration __

6. **EARLY SIGNS:** __ Appears dazed or stunned __ Is confused about events __ Answers questions slowly __ Repeats Questions __ Forgetful (recent info)

7. **Seizures:** Were seizures observed? __ No __ Yes __ Detail __

---

### B. Symptom Check List

**PHYSICAL (10)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache</td>
<td>0-1</td>
</tr>
<tr>
<td>Nausea</td>
<td>0-1</td>
</tr>
<tr>
<td>Vomiting</td>
<td>0-1</td>
</tr>
<tr>
<td>Balance problems</td>
<td>0-1</td>
</tr>
<tr>
<td>Dizziness</td>
<td>0-1</td>
</tr>
</tbody>
</table>

**SLEEP (4)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficulty remembering</td>
<td>0-1</td>
</tr>
<tr>
<td>Trouble falling asleep</td>
<td>0-1</td>
</tr>
</tbody>
</table>

**COGNITIVE (4)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficulty concentrating</td>
<td>0-1</td>
</tr>
<tr>
<td>Sleep more than usual</td>
<td>0-1</td>
</tr>
</tbody>
</table>

**EMOTIONAL (4)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory loss</td>
<td>0-1</td>
</tr>
</tbody>
</table>

**COGNITIVE Activity** __ Yes __ No __ N/A

**SLEEP Total (0-22)**

---

### C. Risk Factors for Protracted Recovery

Check all that apply:

<table>
<thead>
<tr>
<th>Item</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior treatment for headache</td>
<td>1</td>
</tr>
<tr>
<td>History of migraine headache</td>
<td>1</td>
</tr>
<tr>
<td>Family history of headache</td>
<td>1</td>
</tr>
</tbody>
</table>

**Developmental History**

<table>
<thead>
<tr>
<th>Item</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning disabilities</td>
<td>1</td>
</tr>
<tr>
<td>Attention-Deficit/Hyperactivity Disorder</td>
<td>1</td>
</tr>
<tr>
<td>Other developmental disorder</td>
<td>1</td>
</tr>
</tbody>
</table>

**Psychiatric History**

<table>
<thead>
<tr>
<th>Item</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anxiety</td>
<td>1</td>
</tr>
<tr>
<td>Depression</td>
<td>1</td>
</tr>
<tr>
<td>Other psychiatric disorder</td>
<td>1</td>
</tr>
</tbody>
</table>

---

### D. RED FLAGS for acute emergency management:

Refer to the emergency department with sudden onset of any of the following:

- * Headaches that worsen
- * Looks very drowsy/can’t be awakened
- * Can’t recognize people or places
- * Neck pain
- * Seizures
- * Repeated vomiting
- * Increasing confusion or irritability
- * Unusual behavioral change
- * Focal neurologic signs
- * Stumbled speech
- * Weakness or numbness in arms/legs
- * Change in state of consciousness

---

### E. Diagnosis (ICD-10):

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S06.0X0A</td>
<td>Concussion without LOC S06.0X1A</td>
</tr>
<tr>
<td><em>No diagnosis</em></td>
<td></td>
</tr>
</tbody>
</table>

---

### F. Follow-Up Action Plan

Complete ACE Care Plan and provide copy to patient/family.

**No Follow-Up Needed**

<table>
<thead>
<tr>
<th>Item</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of next follow-up</td>
<td>1</td>
</tr>
</tbody>
</table>

**Referral:**

- Neurosurgery
- Neurology
- Sports Medicine
- Psychiatrist
- Other

**Emergency Department**

---

ACE Completed by: __________________________ MD RN NP PhD ATC

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A concussion (or mild traumatic brain injury (MTBI)) is a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces secondary to direct or indirect forces to the head. Disturbance of brain function is related to neurometabolic dysfunction, rather than structural injury, and is typically associated with normal structural neuroimaging findings (i.e., CT scan, MRI). Concussion may or may not involve a loss of consciousness (LOC). Concussion results in a constellation of physical, cognitive, emotional and sleep-related symptoms. Symptoms may last from several minutes to days, weeks, months or even longer in some cases.

ACE Instructions

The ACE is intended to provide an evidence-based clinical protocol to conduct an initial evaluation and diagnosis of patients (both children and adults) with known or suspected MTBI. The research evidence documenting the importance of these components in the evaluation of an MTBI is provided in the reference list.

A. Injury Characteristics:

1. Obtain description of the injury - how injury occurred, type of force, location on the head or body if force transmitted to head. Different biomechanics of injury may result in different symptom patterns (e.g., occipital blow may result in visual changes, balance difficulties).

2. Indicate the cause of injury. Greater forces associated with the trauma are likely to result in more severe presentation of symptoms.

3/4. Amnesia: Amnesia is defined as the failure to form new memories. Determine whether amnesia has occurred and attempt to determine length of time of memory dysfunction – before (retrograde) and after (anterograde) injury. Even seconds to minutes of memory loss can be predictive of outcome. Recent research has indicated that amnesia may be up to 4-10 times more predictive of symptoms and cognitive deficits following concussion than is LOC (less than 1 minute).1

5. Loss of consciousness (LOC) - If occurs, determine length of LOC.

6. Early signs, if present, ask the individuals who know the patient (parent, spouse, friend, etc) about specific signs of the concussions' MTBI that may have been observed. These signs are typically observed early after the injury.

7. Inquire whether seizures were observed or not.

B. Symptom Checklist:2

1. Ask patient (and/or parent, if child) to report presence of the four categories of symptoms since injury. It is important to assess all listed symptoms as different parts of the brain control different functions. One or all symptoms may be present depending upon mechanisms of injury.2 Record 1 for Yes or 0 for No for their presence or absence, respectively.

2. For all symptoms, indicate presence of symptoms as experienced within the past 24 hours. Since symptoms can be present premorbidly/at baseline (e.g., inattention, headaches, sleep, sadness), it is important to assess change from their typical presentation.

3. Scoring: Sum total number of symptoms present per area, and sum all four areas into Total Symptom Score (score range 0-22). (Note: Most sleep symptoms are only applicable after a night has passed since the injury. Drowsiness may be present on the day of injury.) If symptoms are new and present, there is no lower limit symptom score. Any score > 2 indicates positive symptom history.

4. Excitement: Inquire whether any symptoms worsen with physical (e.g., running, climbing stairs, bike riding) and/or cognitive (e.g., academic studies, multi-tasking at work, reading or other tasks requiring focused concentration) exertion. Clinicians should be aware that symptoms will typically worsen or re-emerge with exertion, indicating incomplete recovery. Over-exertion may protract recovery.

5. Overall Rating: Determine how different the person is acting from their usual self. Circle 0 (Normal) to 6 (Very Different).

C. Risk Factors for Protracted Recovery: Assess the following risk factors as possible complicating factors in the recovery process.

1. Concussion history: Assess the number and date(s) of prior concussions, the duration of symptoms for each injury, and whether less biomechanical force resulted in re-injury. Recent research indicates that cognitive and symptom effects of concussion may be cumulative, especially if there is minimal duration of time between injuries and less biomechanical force results in subsequent concussion (which may indicate incomplete recovery from initial trauma).2

2. Headache history: Assess personal and/or family history of diagnosis/treatment for headaches. Recent research indicates headache (migraine in particular) can result in protracted recovery from concussion.5-11

3. Developmental history: Assess history of learning disabilities, Attention-Deficit/Hyperactivity Disorder or other developmental disorders. Recent studies indicate the possibility of a longer period of recovery with these conditions.

4. Psychiatric history: Assess for history of depression/mood disorder, anxiety, and/or sleep disorder.14-16

D. Red Flags: The patient should be carefully observed over the first 24-48 hours for these serious signs. Red flags are to be assessed as possible signs of deteriorating neurological functioning. Any positive report should prompt strong consideration of referral for emergency medical evaluation (e.g. CT Scan to rule out intracranial bleed or other structural pathology).

E. Diagnosis:

The following ICD-10 diagnostic codes may be applicable.

S06.00XA (Concussion, with no loss of consciousness) – Positive injury description with evidence of forcible direct/ indirect blow to the head (A10a); plus evidence of active symptoms (B) of any type and number related to the trauma (Total Symptom Score >0); no evidence of LOC (A5), skull fracture or intracranial injury (A15).

S06.01XA (Concussion, with brief loss of consciousness < 30 minutes) - Positive injury description with evidence of forcible direct/ indirect blow to the head (A10a); plus evidence of active symptoms (B) of any type and number related to the trauma (Total Symptom Score >0); positive evidence of LOC (A5), skull fracture or intracranial injury (A15).

S06.03XA (Concussion, unspecified) - Positive injury description with evidence of forcible direct/ indirect blow to the head (A10a); plus evidence of active symptoms (B) of any type and number related to the trauma (Total Symptom Score >0); unclear/injury details; unclear evidence of LOC (A5), no skull fracture or intracranial injury.

Other Diagnoses – If the patient presents with a positive injury description and associated symptoms, but additional evidence of intracranial injury (A15) such as from neuroimaging, a moderate TBI and the diagnostic category of S06.880A (Intracranial injury) should be considered.

F. Follow-Up Action Plan: Develop a follow-up plan of action for symptomatic patients. The physician/clinician may decide to (1) monitor the patient in the office or (2) refer them to a specialist. Serial evaluation of the concussion is critical as symptoms may resolve, worsen, or ebb and flow depending upon many factors (e.g., cognitive/ physical exertion, comorbidities). Referral to a specialist can be particularly valuable to help manage certain aspects of the patient’s condition. (Physician/clinician should also complete the ACE Care Plan included in this tool kit.)

1. Physician/clinician serial monitoring - Particularly appropriate if number and severity of symptoms are steadily decreasing over time and/or fully resolve within 3-5 days. If steady reduction is not evident, referral to a specialist is warranted.

2. Referral to a specialist – Appropriate if symptom reduction is not evident in 3-5 days, or sooner if symptom profile is concerning in type/severity.

- Neuropsychological Testing can provide valuable information to help assess a patient’s brain function and impairment and assist with treatment planning, such as return to play decisions.

- Physician Evaluation is particularly relevant for medical evaluation and management of concussion. It is also critical for evaluating and managing focal neurologic, sensory, vestibular, and motor concerns. It may be useful for medication management (e.g., headaches, sleep disturbance, depression) if post-concussive problems persist.
Appendix 9
Recovery Trajectories Stratified by Sex

(A) Male recovery trajectory

(B) Female recovery trajectory

These images depict the relationship between SDNN and PCSI total score across days post injury, stratified by sex. Here, the male recovery trajectory appears to follow the same trajectory of the group at large (as described in Chapter 4, results section) whereas the female recovery trajectory appears to be less salient in the dips and peaks across days post injury.
These images depict the relationship between RMSSD and PCSI total score across days post injury, stratified by sex. Here, the male recovery trajectory appears to follow the same trajectory as the female recovery trajectory whereby there is an initial decrease in HRV until day 30, followed by increases until day 75, followed by a plateau.
These images depict the relationship between HF and PCSI total score across days post injury, stratified by sex. Here, the recovery trajectory appears to be less apparent in males and more apparent in females, whereby males demonstrate an initial decrease is seen until day 30, followed by increases until day 60, followed by a plateau.
These images depict the relationship between pNN50 and PCSI total score across days post injury, stratified by sex. Here, the recovery trajectory appears to be similar within both males and females, an initial decrease until day 30, followed by increases until day 75/90 for males and females respectively, followed by a plateau.
Appendix 10
Mindfulness-based Yoga Consent Forms

STUDY INFORMATION CONSENT FORMS

Informed Consent Form to Participate in a Research Study

Flesch-Kincaid Grade level 7.5

A Pilot Study on the Effect of Mindfulness-based Yoga on Youth with Persistent Concussion Symptoms: Bridging Neurophysiological and Functional Outcomes

Principal Investigator:

Dr. Nick Reed, PhD, MScOT, OT Reg. (Ont).

Clinician Scientist and Occupational Therapist

Concussion Research Centre

Blooorview Research Institute, Holland Blooorview Kids Rehabilitation Hospital

Rehabilitation Science Institute, University of Toronto

Associate Professor, Department of Occupational Science and Occupational Therapy

University of Toronto

Project Members:

- Melissa Paniccia, MScOT, OT Reg. (Ont)., PhD student (project lead)
- Ruby Knafo, MScOT, OT Reg. (Ont)., Certified Yoga Instructor
- Alliana Bagtas, MScOT candidate, University of Toronto
Dear Youth and Parent/Guardian,

My name is Nick Reed. I am part of a research study at Bloorview Research Institute at Holland Bloorview that is testing an intervention to help youth with lasting concussion symptoms. We would like to invite you to try out an intervention to see if this can be offered for other youth. Before agreeing to take part in this study, it is important that you understand how you will be involved. This consent form provides you with information to help you make an informed choice.

What is the study about?

We want to learn about a new way to treat youth between the ages of 13-18 years old with lasting concussion symptoms. We want to learn about how this treatment may help them feel better. We are also looking at how the heart responds to this treatment. We are looking at the heart because it helps us measure stress in a person. We are testing youth who are experiencing symptoms for more than 1 month. The treatment takes place in a group and is called mindfulness-based yoga (MBY). MBY contains different physical yoga poses and a new way to think about your thoughts. MBY has shown to be helpful in adults with similar issues to concussion. We do not know if this will work because this is an early study. It will provide us with information to do a larger study. Our plan is to have 10 youth in this group-based study.

How will you be involved in this study?

We would like to invite you to participate in this study. You must show me that you understand what you will have to do to take part in this study. You must show me that you understand the risks and benefits. If you cannot do this, you cannot participate in the study. Parents are not involved in this study, however, they are part of the consent process to maintain communication...
and transparency when requesting background information at the first initial visit. Background information requested from parents will include details of concussion injury, medications and previous intervention/treatment history. No other information will be collected from parents.

In total, you will have 11 visits at Holland Bloorview. Three out of the 11 visits will be to collect information from you. Eight out of the 11 visits will be MBY sessions.

This is what youth will be asked to do:

**Youth will be asked to come to Holland Bloorview for 3 visits** (before beginning the intervention, after the intervention is complete and 3 months after the intervention is complete). All of these will take place in the Holland Bloorview Hospital. Each of these sessions will take approximately 1 hour – 1 hour, 15 minutes.

**In the first visit (before beginning the intervention):**

- We will ask you to complete paper and pencil questionnaires about your symptoms, daily activities and how you feel.
- We will ask you to complete some physical tests (balance and hand grip strength)
- We will ask you questions about your health. For example, your history of concussion, other treatments you have received.
- We will also ask you questions about your current concussion and how it affects school, sport and other daily activities.
- We will ask you to take measurements of height, weight, age and sex.
- We will ask you to wear a basic heart rate monitor around your chest for 24 hours (each time you visit, we will explain how to wear and use it)

**At each of the last two visits, (after the intervention is complete and 3 months following the intervention):**

- We will ask you to complete paper and pencil questionnaires about your symptoms, daily activities and how you feel.
- We will ask you to complete the physical tests (balance and hand grip strength)
- We will ask you to wear a basic heart rate monitor around your chest for 24 hours (each time you visit, we will explain how to wear and use it)

This information will help us understanding how youth with concussion are similar or different from youth without a concussion.

**All youth will participate in the group MBY treatment.**

- There will be 8 sessions, 1 session each week (total of 8 weeks). This will occur in a group setting.
• Each session will take **1 hour. It is strongly recommended that you wear comfortable gym clothes at each MBY session. You will also be required to do the session barefoot to avoid slipping off the yoga mat with your socks.**

• You will come to Holland Bloorview for each of the 8 sessions. The beginning of the intervention will take place once we have enough participants to run the group.

• A yoga instructor will lead each of the 8 sessions with instructions along the way to make sure you feel comfortable.

• An occupational therapist/PhD researcher will be at every session. Before each intervention session, she will fit you with a heart rate chest strap and watch to take recordings of your heart rate. You will be asked to wear these for 24 hours and can return the heart rate items at the next session.

• At the end of MBY intervention, we will ask youth to complete a satisfaction survey on their experience. This will be done at Holland Bloorview after you finish your 8 sessions of MBY. This will take approximately **30 minutes.**

**A note on the heart rate monitor and equipment:** At each of the 11 sessions at Holland Bloorview, you will be required to wear a non-invasive, easy-to-wear heart rate monitor. The equipment includes a sensor, which clips onto an adjustable chest strap and a watch. You will receive instruction on how to use this device. At the end of the study you will need to return all equipment (sensory, chest strap and watch).

In summary, the 11 sessions at Holland Bloorview are as follows:

<table>
<thead>
<tr>
<th>MBY sessions</th>
<th>Pre-intervention</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
<th>Post-intervention</th>
<th>3month follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Questionnaires on activity level, symptoms</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 hour 15 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Physical Measures</strong></td>
<td>1 hour 15 minutes</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MBY Intervention</strong></td>
<td></td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wear heart rate chest strap (for 24 hours)</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A note on the heart rate monitor and equipment: At each of the 11 sessions at Holland Bloorview, you will be required to wear a non-invasive, easy-to-wear heart rate monitor. The equipment includes a sensor, which clips onto an adjustable chest strap and a watch. You will receive instruction on how to use this device. At the end of the study you will need to return all equipment (sensory, chest strap and watch).
**Will anyone know what I say?**

All of the information we collect about you and your responses will always be kept private. Throughout the study, your name will be replaced with a research identification number. This identification number is also private and the only people who have access to it are the research study team.

It is important to note that because the sessions will be held in a group setting, I will ask other youth who attend not to share who took part in the study. This may not be guaranteed.

No information we collect will be made public that might identify you, unless required by law. For example, we have a legal duty to report suspected child abuse and potential harm to self or others.

If the results are published, your names and identifying information will not be used.

We will keep all of the information collected in a locked filing cabinet in the Holland Bloorview Concussion Centre. When data is placed onto the computers, a protected password will be applied to the files that only the researchers will know. We must keep the research data for 7 years. This is a requirement of the hospital.

**Do I have to do this?**

You do not need to participate in this study. It is okay if you decide not to take part. If you do decide to take part, you can change your mind at any time. If you decide to no longer take part in the study, the data we collect about you will not be used for research purposes. You can let Melissa Paniccia (PhD student) or Dr. Nick Reed know by email, telephone or in person that you no longer wish to participate. Whatever you decide will not affect the services you get from Holland Bloorview.
New information that we get while we are doing this study may affect your decision to take part in this study. If this happens, we will tell you about this new information and we will ask you if you would still like to take part in the study.

**What are the risks and benefits?**

This research may help us understand whether MBY may help youth with lasting concussion symptoms. You may experience reduced symptoms and increased participation in your daily life activities by taking part in this study.

Because you have lasting concussion symptoms, you may experience a worsening of symptoms (e.g. headache, fatigue) while taking part in this study. These symptoms may happen in approximately 10-20% of youth and can likely be reversed with different yoga poses with chairs, adequate rest breaks, or termination in the session. If you experience an increase in symptoms or do not feel well, please tell the PhD student (Melissa Paniccia) or the yoga instructor (Ruby Knafo) that you are experiencing an increase in symptoms. We will then ask you a few questions to determine if you can try taking a break, using a chair or stop participation in the session. We will make this decision based on you letting us know how you have managed the symptoms in the past. If what you experience in that moment is above and beyond your current experience with symptoms, we will ask that you no longer participate in that particular MBY session. In the event of worsening symptoms, all testing/intervention sessions will be stopped immediately and resumed only after a minimum of 24 hours of rest and symptom resolution. If symptoms do not get better and/or you no longer want to participate in the study, that is okay.

An emotional reaction may also occur when completing the paper and pencil questionnaires as reflecting on limited participation in daily activities may be upsetting. The researcher is also an Occupational Therapist and will be there to guide and clarify concepts on these questionnaires. You are not obligated to complete any questionnaires you are not comfortable with. There will be no negative consequences if you choose to stop testing. If there are tasks during the testing/intervention that you do not want to participate in, that is okay.
The results we gather from this study will be presented with the results from other participants as well. No identifiable information will be made available to the public. Individual results from the testing and intervention can be shared with you if you like. At the end of the study, if you wish to see your results before publication, you can email or call Melissa Paniccia (PhD student) and she will set a meeting with you to go over your results. As this is not a clinical treatment, she will not be able to interpret what the results mean.

You still have your legal rights in the event of research-related harm, if you decide to take part in this study.

**Do the investigators have any conflicts of interest?**

The MBY instructor, Ruby Knafo is a study co-investigator on this research team and has her own yoga studio. However, participants are under no obligation to take yoga classes with her/from her studio.

I, Nick Reed (Principal Investigator), and other members of the research study do not have any conflicts of interest to declare.

**Reimbursement:**

Youth participants will be given a $10 gift card for each of the three visits where we collect questionnaire information (for a total of $30 dollars). Parking will also be reimbursed for each of the 11 visits. This gift card is a token of thanks for helping us with this study.

**What if I have questions?**

Participants and parents/guardians can contact me to explain anything that is not understood. My phone number is [redacted]. I can also be reached by email at [redacted]. You can also reach the PhD student/study investigator, Melissa Paniccia, by phone at [redacted].
If you have any questions about your rights as a research participant, please feel free to contact the Research Ethics Board at Holland Bloorview Kids Rehabilitation Hospital by phone at 416-425-6220 or by email at reb@hollandbloorview.ca.

Thank you for considering taking part with this research study.

Yours Truly,

Nick Reed, PhD, MScOT, OT Reg. (Ont.)
Clinician Scientist and Occupational Therapist
Concussion Centre
Bloorview Research Institute
Holland Bloorview Kids Rehabilitation Hospital
Phone: 416.425.6220 ext. 3861
Email: nreed@hollandbloorview.ca
INFORMED CONSENT FORM
HOLLAND BLOORVIEW KIDS REHABILITATION HOSPITAL

Re: A Pilot Study on the Effect of Mindfulness-based Yoga on Youth with Persistent Concussion Symptoms: Bridging Neurophysiological and Functional Outcomes

Please complete this form below and return it to the researcher. You will receive a signed copy of this form.

By signing this form, I confirm that:

• Melissa Paniccia (PhD student/study investigator) explained this study to me and answered all of my questions.
• I read the attached Informed Consent Form dated _____________ and understand what this study is about.
• I understand the known risks and benefits of participating in this research study.
• I understand that my child or I may drop out of the study at any time. My decision about taking part in the study will not affect the services my child and I get at Holland Bloorview.
• I am free now, or in the future to ask questions about the study.
• I know that study records related to my child will be kept confidential except as described in this form.
• I understand that information that identifies my child or family will not be shared with anyone without first asking my permission.
• I agree to participate in this study and allow my child to participate.

_________________________            __________________________        _________
Youth’s Name (please print)       Signature                        Date
Parent’s Name (please print) | Signature | Date
---|---|---

I have explained this study to the above participant/parent and have answered all their questions.

Name of Person Obtaining Consent | Signature | Date
Mindfulness-based Yoga Recruitment Flyer

Participate in Research
Mindfulness-based Yoga for Youth with Persistent Concussion Symptoms

Principal Investigator:
Dr. Nick Reed, PhD, Occupational Therapist
email: nreed@hollandbloorview.ca
phone: 416-425-6220, ext. 3861

Centre for Leadership
In Acquired Brain Injury

CONTACT INFORMATION:
For more information about this study, or to participate, please contact:

Melissa Paniccia,
Occupational Therapist, PhD student
email: mpaniccia@hollandbloorview.ca
phone: 416-425-6220, ext. 3564

ARE YOU A YOUTH WHO’S HAD A CONCUSSION? STILL EXPERIENCING SYMPTOMS FOR MORE THAN 1 MONTH?

What is this study about?
This research study is testing a mindfulness-based yoga intervention that has not been done with youth who have persistent concussion symptoms. Our goal is to test this intervention to see if it can improve how youth participate in daily activities like going to school, playing sports or being with friends and family.

Who can participate?
We are looking for youth who are
- Between 13-18 years old
- Experiencing concussion symptoms for greater than 1 month

What’s involved?
- Three visits to Holland Bloorview Kids Rehabilitation Hospital’s Concussion Centre
- 8 weeks of intervention delivered at Holland Bloorview, once per week for 45mins-1 hour
- Participants will complete a series of questionnaires on concussion symptoms and participation in daily activities
- Participants will wear a non-invasive heart rate monitor for a total of eleven, 24-hour periods.

Potential Benefits?
Participants can potentially increase their participation in daily activities and be better able to manage their concussion symptoms.

Potential Risks?
Post-concussion symptoms may occur during the intervention sessions and participants will be able to take breaks or stop participating in the session or study.

Participants will receive a $10 gift card at each of the three visits to Holland Bloorview ($30.00 total). All parking costs per visit will be reimbursed.

Bloorview Research Institute
Canada’s Only Hospital-Based Childhood Disability Research Institute

Holland Bloorview
Kids Rehabilitation Hospital
## Appendix 12

### Self-Efficacy Questionnaire for Children

#### Self-Efficacy Questionnaire for Children (SEQ-C)

<table>
<thead>
<tr>
<th>Item</th>
<th>1 Not at all</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5 Very well</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How well can you get teachers to help you when you get stuck on schoolwork?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2. How well can you express your opinions when other classmates disagree with you?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3. How well do you succeed in cheering yourself up when an unpleasant event has happened?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4. How well can you study when there are other interesting things to do?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5. How well do you succeed in becoming calm again when you are very scared?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6. How well can you become friends with other children?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7. How well can you study a chapter for a test?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8. How well can you have a chat with an unfamiliar person?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9. How well can you prevent to become nervous?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10. How well do you succeed in finishing all your homework every day?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11. How well can you work in harmony with your classmates?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12. How well can you control your feelings?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13. How well can you pay attention during every class?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14. How well can you tell other children that they are doing something that you don’t like?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15. How well can you give yourself a pep-talk when you feel low?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16. How well do you succeed in understanding all subjects in school?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>17. How well can you tell a funny event to a group of children?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18. How well can you tell a friend that you don’t feel well?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19. How well do you succeed in satisfying your parents with your schoolwork?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20. How well do you succeed in staying friends with other children?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21. How well do you succeed in suppressing unpleasant thoughts?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22. How well do you succeed in passing a test?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>23. How well do you succeed in preventing quarrels with other children?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24. How well do you succeed in not worrying about things that might happen?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Scoring

A total self-efficacy score can be obtained by summing across all items. Items 1, 4, 7, 10, 13, 16, 19, and 22 = Academic self-efficacy
Items 2, 6, 8, 11, 14, 17, 20, and 23 = Social self-efficacy
Items 3, 5, 9, 12, 15, 18, 21, and 24 = Emotional self-efficacy

Key references


Note
Appendix 13

Godin Leisure-Time Exercise Questionnaire

GODIN LEISURE-TIME EXERCISE QUESTIONNAIRE

1. **BEFORE YOUR CONCUSSION**, during a typical 7-day period (one week), how many times on average do you do the following kinds of exercise for **more than 15 minutes** during your free time.

   **A) STRENUOUS EXERCISE (HEART BEATS RAPIDLY)**
   E.g. running, jogging, hockey, football, squash, basketball, cross country skiing, judo, vigorous swimming, long distance cycling

   **B) MODERATE EXERCISE (NOT EXHAUSTING)**
   E.g. fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, dancing

   **C) MILD EXERCISE (MINIMAL EFFORT)**
   E.g. Yoga, archery, bowling, golf, snow-mobiling, easy walking

   Times Per Week

2. **BEFORE YOUR CONCUSSION**, during a typical 7-day period (1 week), in your leisure time, how often do you engage in any regular activity long enough to work up a sweat (heart beats rapidly)?
   Please circle one.

   **OFTEN**  **SOMETIMES**  **NEVER/RARELY**
1. CURRENTLY, during a typical 7-day period (one week), how many times on average do you do the following kinds of exercise for **more than 15 minutes** during your free time.

<table>
<thead>
<tr>
<th></th>
<th>Times Per Week</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A) STRENUOUS EXERCISE (HEART BEATS RAPIDLY)</strong></td>
<td></td>
</tr>
<tr>
<td>E.g. running, jogging, hockey, football, squash, basketball, cross country skiing, judo, vigorous swimming, long distance cycling</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Times Per Week</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B) MODERATE EXERCISE (NOT EXHAUSTING)</strong></td>
<td></td>
</tr>
<tr>
<td>E.g. fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, dancing</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Times Per Week</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C) MILD EXERCISE (MINIMAL EFFORT)</strong></td>
<td></td>
</tr>
<tr>
<td>E.g. Yoga, archery, bowling, golf, snow-mobiling, easy walking</td>
<td></td>
</tr>
</tbody>
</table>

2. CURRENTLY, during a typical 7-day period (1 week), in your leisure time, how often do you engage in any regular activity long enough to work up a sweat (heart beats rapidly)?

Please circle one.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>OFTEN</td>
<td>SOMETIMES</td>
<td>NEVER/RARELY</td>
</tr>
</tbody>
</table>
INSTRUCTIONS

In this excerpt from the Godin Leisure-Time Exercise Questionnaire, the individual is asked to complete a self-explanatory, brief four-item query of usual leisure-time exercise habits.

CALCULATIONS

For the first question, weekly frequencies of strenuous, moderate and light activities are multiplied by nine, five and three, respectively. Total weekly leisure activity is calculated in arbitrary units by summing the products of the separate components, as shown in the following formula:

Weekly leisure activity score = (9*Strenuous) + (5*Moderate) + (3*Light)

The second question is the used to calculate the frequency of weekly leisure-time activities pursued “long enough to work up a sweat” (see questionnaire).

EXAMPLE

Strenuous = 3 times/week

Moderate = 6 times/week

Light = 14 times/week

Total leisure activity score = (9*3) + (5*6) + (3*14) = 99
### Appendix 14

**Mindfulness-based Yoga Components and Session Breakdown**

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mindfulness meditation</td>
<td>Attention is anchored on the sensations of breathing and the body, to notice when the mind wanders, and to bring the attention back to noticing the breath. A detached, non-judgmental way of addressing “wandering” thoughts about one’s thoughts, emotions and sensations of the body is encouraged in an effort to normalize them. Mindfulness mediation occurs at the beginning of each MBY session for 3-5 minutes guided by the yoga instructor.</td>
</tr>
<tr>
<td>Physical yoga postures</td>
<td>Postures include standing, supine, prone and seated postures. MBY sessions will follow the same sequence of postures week to week and will incrementally increase in difficulty by increasing the duration of time spent in each posture.</td>
</tr>
<tr>
<td>Attentional focus and attitude</td>
<td>Focus is brought to the sensations of the breath and body, cultivating sustained attention. Wandering thoughts are re-directed back to noticing breath and sensations. The main focus of beginning sessions of MBY is on attention of the breath and body with neutral judgement (i.e. avoiding negative or positive thoughts). As sessions progress, focus is placed on noticing the wandering mind and adopting a curious and investigative attitude. For example, when exploring the sensations of discomfort while holding a posture, labeling these feelings as “planning,” “remembering,” or simply “thinking” is encouraged. In the final sessions of MBY, emotions are added as another dimension to label their experience/thoughts (e.g. “worry”, “frustration”, “fear”).</td>
</tr>
<tr>
<td>Self Care</td>
<td>Self-care is the act of modifying postures whenever the individual feels it is necessary and to take breaks at any time. In this way, MBY isn’t prescriptive and rather invites the individual to engage in postures that suit them/they feel comfortable with. Alternative postures are offered throughout MBY. External supports (e.g., a chair, the walls) for balance will be encouraged as needed.</td>
</tr>
</tbody>
</table>
SESSION THEME BREAKDOWN FOR MINDFULNESS-BASED YOGA

Materials needed for all sessions: Yoga mats (1 per participant), chairs (one per participant as needed)

Session 1-2, Theme: Anchoring attention to mind and body

Duration: 45 minutes

Begin with 3 minutes of seated meditation, coming back to the breath.

Session description: The first 2 sessions will focus on teaching participants the physical yoga postures. The instructor will use simple and invitational language, and will demonstrate each posture. Participants will also be instructed to focus their attention on their breath, and the physical sensations in their bodies while holding the yoga postures, to develop sustained and focused attention. The instructor will encourage participants to notice when their minds have wandered and to return to noticing breath and sensations, and to bring their attention back to breath and body without judging themselves negatively or positively.

Session 3-5, Theme: Focusing the distracted mind

Duration: 45 minutes

Begin with 3-4 minute seated meditation, followed by yoga practice. Postures will be held for slightly longer than previous weeks to increase challenge.

Session description: Participants guided to notice when their minds have wandered, and to adopt a curious and investigative attitude to their experience. For example, exploring the sensorial qualities of physical sensation in the body whether pleasant or unpleasant (e.g., “itching”, “heat”, “tension”), and to notice thoughts and label them (e.g., “planning”, “remembering”, “thinking”), and to the same with emotions (e.g., “worry”, “frustration”, “fear”) to practice disengaging from automatic associative thinking, and then to return to noticing the breath and the position of the body in the yoga postures.
Session 6-8, Theme: Bringing it all together and “allowing/letting be”

*Duration:* 45 minutes

Begin with 5 minutes seated meditation practice followed by yoga practice.

**Session description:** Participants will be encouraged to notice the wandering mind, acknowledge with acceptance where the mind has gone (thought, emotions, physical sensations), investigate sensations and emotions with curiosity, recognize discomfort and aversion (e.g., fear, avoidance) and its affect on the body and investigate in same way as before and then bring attention back to the breath or the posture. Instructor will guide participants to allow sensations of discomfort or effort to be as they are and to bring awareness to automatic patterns of reactivity, while at the same time emphasizing self-care. Participants will be encouraged to takes cues from their own experience, to change their posture when needed, to rest when needed. Postures will be held for longer in these final 3 sessions to increase physical and mental challenge. **The goal is to foster distress tolerance**, provide opportunities for participants to practice self-care, and allow an opportunity to practice relating in a different way (i.e., observe and respond skillfully, instead of react automatically) to unpleasant stimuli (sensations, emotions).
Appendix 15

Mindfulness-based Yoga Demographic Collection Form

DEMOGRAPHICS FORM

Mindfulness-based Yoga in Youth with Persistent Concussion Symptoms: A Pilot Study

Participant ID Number ______________

Test point: Pre-intervention Intervention Session_______ Post-intervention 3 months

Date: _____________________

Concussion Information

Concussion History: Yes No

Number of Previous Concussions: ____________

Current Injury Date of Occurrence: _________________________

Details of Injury:

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

Current Medications/Purpose:

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________
Other treatments/interventions?

Physical Measures

A. BioSway Balance Assessment

Right Foot: Heel: _______ Foot angle: _______

Left Foot: Heel: _______ Foot angle: _______

Sway Index

Trail 1 – Eyes Open, Foam Surface: _______

Trial 2 – Eyes Closed, Firm Surface: _______

Trial 3 – Eyes Open, Firm Surface: _______

Trial 4 – Eyes Closed, Foam Surface: _______

Sway Index (instability): _______

B. Hand Grip Strength

Dominant Hand: Right    Left

Right Hand:

Trial 1: _______ kg    Trial 2: _______ kg    Trial 3: _______ kg

Left Hand:

Trial 1: _______ kg    Trial 2: _______ kg    Trial 3: _______ kg
Appendix 16

Participation Satisfaction Questionnaire

PARTICIPANT SATISFACTION QUESTIONNAIRE

1. Please rate the quality of mindfulness-based yoga you received:

   4 3 2 1
   Excellent Good Fair Poor

2. Was your experience with mindfulness-based yoga what you thought it would be?

   1 2 3 4
   No, definitely not No, not really Yes, generally Yes, definitely

3. To what extent has mindfulness-based yoga met your needs?

   4 3 2 1
   Almost all of my needs have been met Most of my needs have been met Only some of my needs have been met None of my needs have been met

4. Would you suggest mindfulness-based yoga to friends or family in need of similar help?

   1 2 3 4
   No, definitely not No, not really Yes, generally Yes, definitely

5. How satisfied are you with the help you received?

   1 2 3 4
   Quite dissatisfied Indifferent or mildly satisfied Mostly satisfied Very satisfied

6. Has mindfulness-based yoga helped you better deal with your problems?
<table>
<thead>
<tr>
<th></th>
<th>Yes, it helped a great deal</th>
<th>Yes, it helped somewhat</th>
<th>No, it really didn’t help</th>
<th>No, it seemed to makes things worse</th>
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7. Overall, how satisfied are you with the mindfulness-based yoga you received?

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<thead>
<tr>
<th></th>
<th>Very satisfied</th>
<th>Mostly satisfied</th>
<th>Indifferent or mildly satisfied</th>
<th>Quite dissatisfied</th>
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8. Would you do mindfulness-based yoga again?

<table>
<thead>
<tr>
<th></th>
<th>No, definitely not</th>
<th>No, I don’t think so</th>
<th>Yes, I think so</th>
<th>Yes, definitely</th>
</tr>
</thead>
<tbody>
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Write comments below

________________________________________________________________________
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________________________________________________________________________
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________________________________________________________________________
Appendix 17

Mindfulness-based Yoga Intervention Procedural Flowchart

**Telephone Screen**
- Provide brief explanation on MBY
- Ask questions related to inclusion/exclusion criteria of the study
- Provide timeline of participation in study and what is required by participant
- Schedule appointment for pre-intervention test if participant/family agrees to participate

**Pre-intervention Assessment**
- Explain study in more detail and obtain informed consent/assent from youth and parent
- Complete primary, secondary and demographic variables

**Intervention (8 weeks)**
- 8 weeks of intervention, 1 session per week for 45mins-1 hour

**Post-intervention Assessment**
- Complete primary and secondary variables
- Participants complete post-intervention satisfaction survey

**3-month follow-up Assessment**
- Complete primary and secondary variables

**Recruitment Script**

**Consent/Assent forms**

**Primary outcome measures:** CAPE, SEQ-C, HRV

**Secondary measures:** PSCI, physical (balance, grip strength), GLTE

**Demographics:** Age, sex, height, weight, history of concussion, number of previous concussions

**MBY protocol adapted to suit needs of youth with concussion**

**Participant Satisfaction Questionnaire**

**Primary outcome measures:** CAPE, SEQ-C, HRV

**Secondary measures:** PSCI, physical (balance, grip strength), GLTE

**Demographics:** Age, sex, height, weight, history of concussion, number of previous concussions