Baseline Testing and Beyond:  
A Comprehensive Concussion Assessment Pilot Study

by

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Abstract

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Increased recognition of sport related concussion show that improved assessment methods are needed. Current assessment methods lack objectivity and sensitivity, limiting their efficacy. This study aimed to collect pilot data to evaluate physiological measures (heart rate variability, grip strength and blood pressure) before and after concussion. Routinely used concussion assessment measures of concussion symptoms, cognition, balance, mood, activity and sleep were included to examine the influence of concussion on these parameters. Measures were assessed in Varsity athletes pre and post-concussion. Results from this pilot study indicate that several frequency domain measures of HRV displayed decreased values day 1 post injury compared to baseline. Our findings suggest that HRV may have the potential to be used as an objective measure to indicate concussion. Cognitive and balance scores demonstrated inconsistent patterns when compared to baseline. Mental activity in the acute phase may contribute to prolonged recovery and would benefit from further study.
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1. Introduction

Sport-related concussions are becoming an increasing concern for active individuals. Within the decade there has been greater attention focused on this injury and public awareness continues to grow. Concussion education, from clinicians to athletes, has resulted in improved awareness of the symptoms of concussion. Return to play protocols have been developed to guide individuals as they recover and return to activity. Efforts are continuing to be made in the assessment and treatment of concussion (Aubry et al., 2002; McCrory et al., 2004, 2008, 2013).

One of the major obstacles in concussion assessment is objectively identifying concussion and recovery. The current model has utilized baseline testing to compare post-concussion scores to healthy baselines. Baseline testing involves obtaining scores on relevant tests prior to an injury occurring. This is typically performed at the beginning of an athletic season. In the event of an injury there is a pre-injury benchmark to compare post-concussion scores (Van Kampen et al., 2006).

Both increased awareness and research of concussion has highlighted short and long term consequences associated with improper management (Boake et al., 2006). When a concussion is not recognized and a player returns to sport they are at an increased risk for subsequent injury (Bazarian, Ibolja, Noble-Haeusslein, Potolicchio & Temkin, 2009). It is clear from the literature that multiple concussive injuries in a short time frame have a lengthier recovery time and the prognosis for complete recovery is poorer (Bazarian et al., 2009). There is also evidence to suggest that multiple “sub-concussive” blows may have a cumulative effect which could result in long term consequences (Bazarian et al., 2009). If it is the case that poor management of concussion may lead to long term impairments there is a definite need to explore methods to identify injury. Assessment and recognition techniques need to be objective and have the sensitivity to detect injury when it is present. This will allow athletes who are at risk for further injury to be removed from play but also allow those who have not experienced a concussive injury to return to play if it is safe to do so.
The purpose of this study was to examine the acute response of select physiological parameters following sport-related concussion in varsity student-athletes. This involved developing a protocol to include heart rate variability, blood pressure and grip strength into baseline testing. We also examined concussion symptoms, cognition, balance, mood, activity and sleep data to evaluate their influence on recovery.

Chapter 2 provides a review of current literature that guided the development of this study. Chapters 3 and 4 are structured as independent manuscripts examining specific objectives related to the studies research questions. Chapter 5 contains an embedded case series analysis followed by a general discussion of the thesis in its entirety in chapter 6. Given this organization, material is repeated in the procedure and outcome sections of chapters 3 and 4.
2. Literature Review

2.1. Concussion Definition

The Concussion in Sport Group, an expert multidisciplinary panel, defines concussion as “a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces” (McCrory et al., 2013). It consists of some common features:

1. Concussion may be caused either by a direct blow to the head, face or neck or a blow elsewhere on the body with an “impulsive” force transmitted to the head.

2. Concussion typically results in the rapid onset of short-lived impairment of neurologic function that resolves spontaneously.

3. Concussion may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury.

4. Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course. In a small percentage of cases, however, post-concussive symptoms may be prolonged.

5. No abnormality on standard structural neuroimaging studies is seen in concussion.

Concussion manifests in a host of clinical symptoms (somatic, cognitive, and emotional) that are thought to resolve spontaneously, within 7-10 days (McCrory et al., 2004). This normalization
of symptoms and spontaneous recovery is found in approximately 80-95% of individuals and a small percentage experience prolonged symptoms that may last weeks to months following injury (McCrory et al., 2009; King, 2003; Gagnon, Galli, Friedman, Grilli, & Iverson, 2009; Leddy et al., 2010). Individuals with prolonged symptoms are classified as having post-concussion syndrome. The World Health Organization (WHO) defines post-concussion syndrome as “persistence of three or more of the following symptoms after head injury: headache, dizziness, fatigue, irritability, insomnia, concentration or memory difficulty” (Boake et al., 2005, pg 351).

At the present time there are two evidence-based protocols which have been developed that use exercise, sport specific and balance training to aid recovery in those that are slow to recover following concussion (Gagnon, Galli, Friedman, Grilli, & Iverson, 2009; Leddy et al., 2010). These protocols are the first of their kind to include an exercise formula for symptomatic individuals. It has been shown that individualized, step-wise exercise within the right timeframe is not only safe for symptomatic individuals but has also been shown to improve recovery (Gagnon, Galli, Friedman, Grilli, & Iverson, 2009). Protocols may be enhanced with the addition of a physiological measure that could help guide return to activity protocols. This could allow clinicians to gauge recovery with an objective, individualized measure. Concussion symptoms have been shown to be exacerbated with improper management which increases the likelihood of prolonged recovery (Asplund, McKeag & Olsen, 2004). As a result of prolonged symptoms lasting weeks to months, this group often develops secondary complications as a result of the physical and mental limitations (Giza & Hovda, 2001; Leddy et al., 2007). Current guidelines for individuals with concussion state that physical and mental activity be restricted until symptoms have resolved (McCrory et al., 2013).

2.2. Pathophysiology of Concussion

Following brain trauma, in the animal model, a series of metabolic changes occur at the cellular level (Giza & Hovda, 2001). There are well identified acute changes that occur within one minute following trauma and normalize within 10 days. The acute effects that occur can be grouped into four distinct categories; (1) neurometabolic (Giza & Hovda, 2001), (2)
cerebrovascular (Len & Neary 2011), (3) autonomic control (Rangel-Castill et al., 2008), and (4) structural changes (Lifshitz, Sullivan, Hovda, Wieloch & McIntosh, 2004). The molecular effect of concussion can be described as a cascade of events that occurs over a specific period of time (Giza & Hovda, 2001).

**Neurometabolic**

A series of events triggered by the release of glutamate, an excitatory neurotransmitter, leads to increased glucose metabolism and ultimately a discrepancy between glucose supply and demand (Giza & Hovda, 2001). The release of glutamate causes neurons to depolarize leading to increased levels of calcium entering, and potassium exiting, the cell. This shift in electrical potential along the membrane signals the sodium-potassium pump to try to restore this imbalance. As the sodium-potassium pump attempts to stabilize the membrane potential it uses high levels of ATP, thus creating an increased demand without an increasing supply of glucose (Leddy et al., 2007 & 2010). This process of increasing glucose metabolism is called hyperglycolysis and may be one of the reasons why the brain is vulnerable to repeat injury following trauma (Giza & Hovda, 2001; Gilmer, Roberts, Joy, Sullivan & Scheff, 2009).

**Cerebrovascular**

Cerebrovascular changes are those which occur in the vascular system of the brain. Blood flow has been shown to both increase and decrease following TBI (traumatic brain injury). Several studies have shown an immediate decrease in cerebral blood flow (CBF) (Len & Neary, 2011; Rangel-Castill et al., 2008). There is some controversy regarding cerebral blood flow as results in younger individuals, (<30) have demonstrated an increase in blood flow, followed by a subsequent decrease 1 day thereafter (Len & Neary, 2011). The timeframe of blood flow abnormalities varies depending on severity of injury, but in mild TBI cases, it typically resolves within 1 day (Leddy et al., 2007). Cerebral blood flow is dependent on several factors, two of which are blood pressure and intracranial pressure (ICP) (Len & Neary, 2011). Increases in either blood pressure or intracranial pressure will cause cerebral blood flow to decrease proportionately. Blood pressure and intracranial pressure are known to increase in response to brain trauma (Bouma, Muizelaar, Bandoh & Marmarou, 1992). Intracranial pressure will
increase as a result of the inflammatory process, which will have an effect on cerebral blood flow. Although there are some discrepancies in the findings of cerebral blood flow, it is theoretically conceivable that increases in BP and ICP can cause decreased CBF (Len & Neary, 2011).

Structural Changes

Concussion is generally described as a functional rather than structural injury. Conventional imaging, like CT scan or MRI, rarely displays structural damage (Aubry et al., 2002; McCrory et al., 2004, 2008, 2013). These conventional imaging techniques have been adapted to capture the structural consequence of traumatic brain injury. There have been several animal studies that have documented structural changes in the mitochondria and also through neuronal death (Gilmer et al., 2009; Giza & Hovda, 2004; Greisback, Hovda, Molteni & Gomez-Pinilla, 2004). Experimental brain damage has shown that neuron death occurs directly below the site of trauma and the severity of neuron loss correlates with the depth of injury (Gilmer et al., 2009). This neuronal death is linked to the initial trauma but may be aggravated by secondary complications. Impairments in both the structure and function of the mitochondria have been documented in the animal model (Lifshitz et al., 2004). Mitochondria are the main source of energy for the central nervous system and help to maintain cell membrane potential through calcium regulation (Lifshitz et al., 2004). As previously discussed, following mild TBI, the brain experiences an energy discrepancy which is now further compounded through mitochondrial dysfunction. Animal studies, like that of Giza and Hovda (2004), have helped form the foundation for modifying traditional imaging forms to observe abnormal brain function. Functional magnetic resonance imaging (fMRI) and magnetic resonance spectroscopy (MRS) are two types of imaging that have been shown to display changes following concussion (Dziemianowicz, Kirschen, Pukenas, Laudano, Balcer, & Galetta, 2012). Although both tests indirectly assess brain function they differ in that fMRI tests detect abnormal brain activation patterns whereas MRS measures compounds involved with brain metabolism. The major drawback of these tests is that they are costly and time consuming (Dziemianowicz et al, 2012). The availability of these tests to the majority of individuals is limited.
Autonomic Control

Cerebral autoregulation is a control system that maintains and adjusts blood flow in the brain. This regulation is required to accommodate changes in systemic pressure (Len & Neary, 2011; Leddy et al., 2007; Rangel-Castill et al., 2008). This system is controlled by the autonomic nervous system and varies the diameter of blood vessels to adjust blood flow. This function involves the cooperation of the sympathetic and parasympathetic systems of the autonomic nervous system (Len & Neary, 2011; Leddy et al., 2007). Several studies have evaluated heart rate variability as a means of examining the relationship between the autonomic nervous system and cardiovascular systems following TBI. It has been shown that cerebral autoregulation is impaired up to 14 days following traumatic brain injury (Gall et al., 2004a/b).

2.3. Concussion Baseline Testing

Baseline testing is a common clinical practice that compares post-injury with pre-injury scores on a given test or series of tests. The theoretical underpinning opines that scores will return to baseline once recovery from concussion has been achieved. This theory is somewhat flawed when applied to concussion assessment as research has not determined if there are long term consequences that may prevent scores from returning to baseline (Bazarian et al., 2009).

2.4. Symptom Evaluation

At its inception, concussion was regarded as an injury that was identified in a subjective manner (Aubry et al., 2002). As a result, it was first measured through the assessment and measurement of subjective symptoms. Although some symptoms (e.g. headache) are more prevalent than others, there is a high level of variability and severity. Concussion symptoms vary from person to person and between subsequent concussions (Aubry et al., 2002). There have been several scales developed to inventory concussion symptoms. Subjective symptoms have been well documented in the literature and represent a useful tool to evaluate individuals following concussion (Aubry et al., 2002; McCrory et al., 2004, 2008, 2013). However, underreporting of concussion is prevalent in athletic competition and athletes have been found to downplay symptoms in order to continue playing (Aubry et al., 2002).


2.5. Neuropsychological testing

Subjective symptoms continue to be used in the assessment of concussion. They do not however represent the only method of assessment as was previously the case. A lack of recognition of concussion symptoms (Aubry et al., 2002), the stigma associated with concussion and the intentional misrepresentation of symptoms to accelerate return to play decisions (McCrory et al., 2008) resulted in the use of neuropsychological (NP) and cognitive testing to assess brain functions that may be impaired following concussive injury.

Neuropsychological testing involves a specifically defined task that measures a psychological function which is linked to a specific region of the brain (Randolph, McCrea, & Barr, 2005). NP testing provides objective means to measure the clinical manifestation of concussion (McCrory et al., 2004, 2008, 2013). When performed at baseline (pre-injury) NP testing provides a useful tool for comparison following concussion (Schneiders, Sullivan, Gray, Hammond-Tooke & McCrory, 2010). Furthermore the implementation of NP testing revealed that subjective symptom improvement was not always accompanied by cognitive recovery (McCrory et al., 2008). The majority of individuals experience symptom recovery prior to cognitive recovery (McCrory et al., 2008); however there have been cases where the reverse is true (McCrea et al., 2009). This was a significant discovery as return to play decisions were previously based on symptoms only. As a result it was possible that some individuals who experienced a concussion were returned to sport with cognitive deficits that could potentially put them at risk of re-injury (McCrea et al., 2008). NP testing has revealed multiple psychological functions that are impaired following concussion including; verbal and visual memory, cognitive function, processing speed, reaction time, balance and coordination (Bazarian et al., 2009). NP testing has provided clinicians with a more objective method to assess the neural impact of. At the present time there is a lack of sufficient evidence to support NP testing as a gold-standard (Gardner, Shores, Batchlor & Honan, 2012). Clinicians must continue to rely on a combination of factors and make individual decisions regarding each athlete prior to making return to play decisions (McCrory et al., 2013).
2.6. **Balance Evaluation**

Recent research has shown that various categories of motor function are influenced following concussive injury (Fait et al., 2013; Guskiewicz, 2003; Parker, Osternig, van Donkelaar & Chou, 2007; Schneiders et al., 2010). The impairment of motor function is of critical importance because returning an athlete to play with motor deficits affects athletic performance and increases the risk of re-injury, concussive or otherwise. Motor function deficits are at the root an impairment of neuromuscular control. Balance was one of the first components of motor function to be included in the assessment of concussion (Guskiewicz, 2003). Aside from the immediate and overt balance disturbances that are sometimes evident following concussive injury, there is evidence of prolonged balance deficits both in the short and long term (Guskiewicz, 2003; Fait, Swaine, Cantin, Leblond & McFadyen, 2013). A number of tools have been used in the assessment of balance following concussion. The Balance Error Scoring System (BESS) which is included in the SCAT-2 was developed as a means to assess postural stability (McCrory et al., 2013). Prior to this test, postural stability was tested with the use of a force plate which measured the sway of an individual’s centre of gravity (McCrea et al., 2009). This form of technology although highly reliable has little practical value in the athletic environment and is not cost effective. The benefits of the BESS are that it is cost effective and does not require sophisticated technology. The reliability and validity of the BESS has been studied (Schneiders, et al., 2010).

2.7. **Sport Concussion Assessment Tool-2 (SCAT2)**

The Sport Concussion Assessment Tool (SCAT) is a baseline testing tool created in 2001 following the first Consensus on Concussion in Sport (Aubry, et al., 2002). This was the first international meeting of a multidisciplinary panel to come to a consensus regarding assessment and management protocols for sport-related concussion. Although this was not the first assessment tool at the time it represented a comprehensive tool that was developed by world experts in the field in a variety of disciplines that was specified for use in the realm of sport-related concussion. Since that time two newer versions have been developed and these newer versions have incorporated research findings to enhance its utility.
The SCAT-2 has 7 components; 1) symptom score, 2) physical signs score, 3) Glasgow Coma Scale (GCS), 4) Maddocks sideline assessment, 5) cognitive evaluation, 6) balance evaluation and 7) coordination exam.

1. Post-Concussion Scale – is a 7 point likert scale to assess subjective symptoms following concussion. The scale contains 22 commonly reported concussion symptoms and was developed by identifying terms athletes used to describe concussive injury. Symptom severity is the sum of all 22 symptoms for a possible symptom severity total of 132 (Piland, Motl, Guskiewics, McCrea & Ferrara, 2006).

2. Physical signs score is an assessment of loss of consciousness if present. One point each is scored if an athlete has loss of consciousness/unresponsiveness or balance problems. A total of 2 points indicates loss of consciousness accompanied by balance problems (Aubry, et al., 2002).

3. The Glasgow Coma Scale is a commonly used tool to evaluate the level of consciousness after head injury. The scale examines eye, motor and verbal responses of patients. A score of 15 (maximum) indicates a fully awake person and a score of 3 (minimum) indicates a deep coma (Barlow, 2012).

4. Maddocks Sideline Assessment was a tool developed by Dr. Maddocks which contain a set of five orientation questions. These questions have been shown to be reliably different between concussed and non-concussed athletes. Inability to answer a Maddocks question indicates the need for further assessment. Questions are targeted toward an athletic population and can be adapted based on the athletes sport. A maximum score of five points indicates complete orientation (Maddocks, Dicker & Saling, 1995).

5. Cognitive Evaluation (Standardized Assessment of Concussion) out of a possible 30 points is calculated by the sum of the orientation, immediate memory, concentration and delayed recall scores (Ragan et al., 2009).
6. Balance Examination (BESS) was developed to assess postural stability. The BESS uses three stance conditions (2 feet, single leg, tandem stance) to assess postural stability (McCrory et al., 2013).

7. Coordination Examination is five repetitions of the finger to nose task. A maximum score of 1 is achieved if the participant successfully completes the task. The finger to nose task is a component of a routine neurocognitive examination (Swaine & Sullivan, 1993).

Each component of the SCAT-2 has been researched as a stand-alone assessment tool. Continued research is necessary to identify if the complete tool is both specific and sensitive to concussion. The tool shows greater sensitivity to more severe forms of concussion (GCS < 15) and is useful in distinguishing mild from moderate TBI (Prasad, 1996).

2.8. Physiological Parameters

It is clear from the literature that there are physiological impairments following concussion. Furthermore, there is a paucity of assessment and recognition techniques for this injury. Examining physiological parameters following concussion is a logical approach. Firstly, it has been shown in the animal model that there are a specific set of physiological changes that have been identified with experimental brain injury (Giza & Hovda, 2001). Secondly, post-concussion research in humans has found impairment in some physiological measures when individuals are considered to have “recovered” from injury (Gall et al., 2004a/b; Leddy et al., 2010). Lastly, there is a need for more objective testing measures in concussion assessment (McCrory et al., 2013). In response to this need, we have identified three physiological measures from the literature that warrant further exploration in the assessment of sport-related concussion.

Heart Rate Variability

Heart rate variability (HRV) is a measure of the variation of time intervals between heart beats (Kamath, Morillo & Upton, 2012). This non-invasive method can establish the connectivity between the autonomic and cardiovascular systems (La Fountaine et al., 2009). HRV emerged
as a quantitative measure of autonomic activity in the early 1960’s. Its use is most recognized in the field of cardiovascular disease in predicting mortality post-infarction (Kamath, Morillo & Upton, 2012). In many disease states such as; heart disease, respiratory disease, stroke, and psychiatric disorders, decreased HRV is associated with poorer outcomes (Kamath et al., 2012). The sympathetic and parasympathetic nervous systems, two divisions of the ANS, largely influence the time interval between heart beats according to neurohormonal changes associated with varying levels of stress and physical fitness (Kamath et al., 2012). HRV also regulates according to a homeostatic mechanism and becomes significantly lowered by stress, including that associated with the presence of tissue or cellular repair (Chen et al., 2011).

Research findings indicate that there are heart rate variability impairments in recently concussed athletes (LaFountaine, Hefferman, Gossett, Bauman & DeMeersman, 2009). It has been established that HRV is sensitive enough to detect changes in asymptomatic, “recovered”, concussed individuals and has the potential to be used to assess physiological recovery from traumatic brain injury (Gall et al., 2004a/b; Leddy et al., 2010). Assessing this variable from pre-injury through recovery would provide a greater understanding of the relationship between the autonomic and cardiovascular systems. Because this system ultimately responds to changes in systemic blood pressure, the latter measure also helps to identify irregularity in function. Furthermore, a recent study identified blood pressure as an indicator of symptom exacerbation in an exercise intervention (Leddy et al., 2010). Because of the complex relationship between blood pressure, intracranial pressure and blood flow (Len & Neary, 2011), there is value in garnering a more complete understanding of its function both pre and post-concussion. Several studies (Gall et al., 2004a/b; Leddy et al., 2010; La Fountaine, Heffernan, Gossett, Bauman, De Meersman, 2009; Su, Kuo, Kuo, Lai & Chen, 2005) have evaluated heart rate variability as a means of examining the relationship between the autonomic nervous system and cardiovascular systems following traumatic brain injury (TBI). These studies examined participants following recovery from concussion and noted neuroautonomic cardiovascular dysfunction compared to age-matched, healthy controls (Gall et al., 2004a/b).
Blood Pressure

Arterial blood pressure is a cardiovascular function regulated by a complex relationship of various components. It is a commonly measured diagnostic tool to assess the arterial pressure at two distinct phases of heart function. Its two components are represented by systolic pressure, the pressure in the arteries during peak ventricular ejection, and diastolic pressure, the pressure just prior to ventricular ejection. Due to the dynamic nature of cardiovascular function, blood pressure is constantly changing during the cardiac cycle. Mean arterial pressure (MAP) is an average blood pressure reading which accounts for the fact that diastole lasts longer than systole. MAP = 2/3(Systolic Pressure) + 1/3(Diastolic Pressure). MAP is the product of cardiac output (CO) and total peripheral resistance (TPR). All changes in MAP are the direct result of changes in CO and/or TPR, both of which are regulated by a series of dynamic mechanisms involving the muscular, cardiovascular, and autonomic nervous systems. Baroreceptors are sensors located in the internal carotid and aortic arteries that are sensitive to pressure and change in pressure. These are the initial sensors responsible for initiating the mechanism to transmit information to the brainstem which houses the cardiovascular control centre (Vander, Sherman & Luciano, 2001).

Autonomic Control of Blood Pressure

The autonomic nervous system (ANS) is a component of the central nervous system (CNS) which automatically controls various functions. It is divided into two subparts known as the parasympathetic and sympathetic systems. These two systems are activated reciprocally via dual innervation. Subtle activation of both systems allows for a more controlled response which is often a requirement of the ANS (Vander, Sherman & Luciano, 2001).

Blood Pressure and Brain Injury

Blood pressure is a commonly measured diagnostic in the hospital setting where moderate and severe head injured patients are generally seen. The majority of individuals with mild traumatic brain injury (mTBI) and concussion generally do not report to the emergency room for assessment (Podlog & Miller, 2011). Because of the large numbers of moderate and severe
TBI’s seen in hospitals, much of the research regarding blood pressure is specific to this population (Shutter & Narayan, 2008; Mitchell et al., 2007). Patients with severe TBI often display increased intracranial pressure (ICP). It was recognized that there is a relationship between ICP and BP in the early 1900’s by Cushing. The Cushing reflex states that increased ICP will lead to increased BP and irregular breathing patterns. Studies to date have noted that this response is generally reserved for patients with severe TBI and that mild and moderate TBI blood pressure readings are usually within normal limits (Shutter & Narayan, 2008). Research by Mitchell et al. (2007), indicate that patients with a Glasgow Coma Scale (GCS) of 3-15 displayed near normal blood pressure readings that were skewed towards higher values. This finding contradicts work by Shutter and Narayan (2008) who found that hypotensive measures of systolic pressure, in severe TBI, was a significant predictor of outcome. Differences in findings may be due to the age range of participants in each study. Loizou and colleagues (2010) noted that differences exist in the child population and that they have displayed an opposite response to what is commonly found in adults post TBI. Despite a variety of findings blood pressure is still routinely used as an important diagnostic tool for moderate to severe TBI patients.

Motor Function

Scientific examination of motor function post-concussion is a relatively new area of study. One of the challenges of assessing injured athletes post-concussion is selecting a valid test that is both clinically relevant and safe to perform while symptomatic. As both physical and mental tasks have been known to aggravate symptoms and delay recovery (Aubry et al., 2002), it is a unique challenge to assess motor function within these limitations. Grip strength, finger tapping and alternating rapid hand movement have all been used to assess motor function in concussed individuals (Haaland, Temkin, Randahl & Dikmen, 1994). Grip strength has been shown to be decreased up to one month in individuals with mild traumatic brain injury (mTBI). Scores were equal to control subjects one year following injury (Haaland et al., 1994). This indicates that recovery of grip strength and the neuromuscular system occurs more than one month following injury. This is a significantly long time period when the majority of athletes would likely have returned to athletic competition. The consequences of returning an athlete to competition with
neuromuscular deficits include increased risk of injury, concussive or otherwise, and decreased performance (McCrorry et al., 2008).

2.9. Clinical Management

Despite the growth of this field from a theoretical perspective, there are few evidence based protocols in the management and treatment of sport related concussions (Gagnon et al., 2009; Leddy et al., 2010; King 2003; Asplund, McKeag & Olsen, 2004). The current consensus on concussion management advocates both physical and mental rest while symptomatic followed by a gradual return to activity (Aubry et al., 2002; McCrory et al., 2004, 2008, 2013). There are several graded return to activity guidelines which generally follow a similar pattern. They begin with light, stationary, aerobic exercise, gradual introduction of sport specific activity followed by non-contact and lastly full contact practice (Aubry et al., 2002; McCrory et al., 2004, 2008, 2013). Appendix 1 contains the return to play stages as created by the Concussion in Sport Group. Each step is intended to challenge the brain with increasing levels of difficulty to determine if it is safe to return to activity (McCrorry et al., 2008). The Concussion in Sport Group (McCrorry et al., 2013) advocates a 6 stage return to play protocol which commences once an athlete is asymptomatic for 24 hours. If an athlete has any recurrence of symptoms during the return to play steps they must wait until asymptomatic for 24 hours to continue (McCrorry et al., 2013).

This return to play strategy is an effective and useful model in the majority of cases where symptom and cognitive recovery occur within 7-10 days (Leddy et al., 2010; McCrory et al., 2008, Gagnon et al., 2009). Current return to play protocols take into consideration the period of vulnerability following a traumatic brain injury and the necessity to gradually return individuals to full activity. Although this methodology incorporates significant aspects of concussion, it takes a somewhat conservative approach which has yet to be validated by evidence based research. This conservative stance has resulted from the high risk of re-injury following concussion (McCrorry et al., 2008), the devastating risk of second impact syndrome (Aubry et al., 2002) and the long term consequences associated with traumatic brain injury (Bazarian et al., 2009). Second impact syndrome is a rare but fatal injury that can occur when repetitive
concussive injuries are sustained. These impacts in a short time frame can cause cerebral swelling which can have a delayed, catastrophic effect (McCrory et al., 2008). Given that recent research suggests that repetitive concussions may lead to decline in cognitive function in later life, caution is a necessity until scientific research can identify reliable, tested methods for clinical management.

2.10. Recovery

To date there is no mutually agreed upon definition of recovery from concussion. Prior to the implementation of cognitive and neuropsychological testing, recovery from concussion was defined by the absence of symptoms (Aubry et al, 2002). However research has shown that there is a discrepancy between symptomatic and cognitive recovery and that neither is sensitive enough to detect concussion or indicate recovery (McCrory et al., 2013).

2.11. The Future of Concussion Assessment

The next step in the evolution of concussion management is identifying objective measures that can assist with diagnosis and return to activity decisions. These markers would provide clinicians with evidence based criteria for identifying concussion and managing day to day activities (mental, social etc.) and indicate readiness to increase levels of activity. Objective markers would allow for a decreased reliance on subjective symptoms and possibly reduce the incidence of individuals experiencing setbacks due to overexertion. Setbacks can have physiological, emotional and social implications especially for active individuals (Berlin, Willem & Deuster, 2006; Gagnon et al., 2009; Leddy et al., 2010). With the implementation of objective markers it would allow a step-wise approach to all activities and possibly prevent prolonged recovery (Asplund et al., 2004). Physiological markers that are easily administered, readily available and rapidly utilized and analyzed offer an efficient and cost effective approach to concussion identification and management. This could provide clinicians with improved management and a more sophisticated and objective approach for returning athletes to activity following concussion.
2.12. Rationale

At the present time there is no test that accurately and objectively assesses concussion in all cases. It is clear from the literature that the high risk of repeated head trauma in a given athletic contest and the long term implications of concussion warrant improved assessment techniques (Bazarian et al., 2009; Boake et al., 2006; King, 2003; McCrory et al., 2013). Physiological measures were chosen based on their ease of administration, analysis and feasibility in the athletic environment. Although there are currently computerized concussion tests and sophisticated balance equipment, these tests are expensive and require expert analysis to be effective (Gardner, Shores, Batchlor & Honan, 2012). As such, simplistic, objective measures that can be quickly and easily used in the athletic environment may provide a better tool for the average clinician or athletic team, especially on the field. An objective measure that can be quickly administered and has a high level of sensitivity would be an ideal measure. Such a measure has the potential to improve identification, assessment and management of sport-related concussions.

Physiological and performance, dependent measures were selected for this study based on a specific set of criteria:

- A standardized and reliable tool that produces an objective, quantitative value,
- Commonly used by those involved in clinical/field care,
- Cost effective and feasible to use in the clinical/field environment,
- Does not require time consuming or expert analysis,
- Evidence of post-concussion impairment from the literature.

These criteria were chosen to increase the real-world, practical application of the research. Commonly used concussion assessment tools and mood questionnaire were selected to provide additional context to physiological and performance measures, as well as to examine the utility of such tools for improving concussion management.
Heart rate variability (HRV) was selected as a primary outcome to examine physiological response to concussion. Due to its ability to quantitatively evaluate the balance between sympathetic and parasympathetic function, its applicability to concussion research is relevant. Furthermore the HRV data collection can be done with an injured athlete at rest and will not exacerbate their condition. In order to capture the full extent of neuroautonomic cardiovascular dysfunction it is essential to obtain baseline measures prior to injury and assess these measures throughout recovery. This longitudinal approach has the potential to identify a physiological diagnostic marker of concussion.

Blood pressure was selected because of its relationship with the autonomic nervous system as well as the influence of intracranial pressure on blood pressure. The response of blood pressure in milder forms of brain injury and concussion appears to display varying findings (Shutter & Narayan, 2008). Although impairments in blood pressure are typically more common in moderate and severe brain injury, the examination in this context was applied to provide a clearer picture of the response of blood pressure in individuals experiencing a concussion.

Grip strength was used as a performance indicator to investigate the impact of concussion on the musculoskeletal system. Evidence suggests that grip strength has been found to be impaired following mild TBI (Haaland et al., 1994). Examination of grip in the context of concussive injury was selected to provide information about the possible strength deficits that may exist following injury.

The Sport Concussion Assessment Tool-2 was selected because it is one of the only concussion assessment tools that is freely available that has been developed by an expert consensus, multidisciplinary panel (McCrory et al., 2013). It is readily used in the clinical and field environment and as such is the tool most widely used to inform assessment and return to play decisions.

The Profile of Moods questionnaire (short form) was administered to enhance the analysis of physiological parameters. The influence of mood on heart rate variability has been well studied
(Keren et al., 2005; Katz-Leurer et al., 2010). The POMS-SF has also been used in the context of post-concussion assessment (Mainwaring et al., 2004).

Activity and sleep logs were added in year two of the study to help analyze physiological data and examine the impact of concussion on sleep and activity. This basic tool was developed to obtain quantitative and qualitative measures of activity and sleep and to better understand their relationship to HRV.

2.13. Objectives

This pilot study aimed to evaluate the usefulness of physiological and performance measures and routinely used concussion assessment measures that may objectively assess concussion and its impact on the neuromuscular, cardiovascular and autonomic nervous systems. This study developed and pilot tested a protocol to collect physiological and performance data during baseline concussion testing to examine the following research question;

What is the acute response of select parameters following sport-related concussion in varsity student athletes?

In order to answer this research question the following objectives were identified;

1. To develop and pilot test a protocol that includes physiological and routinely used concussion assessment measures as part of baseline concussion testing.
2. To analyze how the following measures respond immediately following concussion.
   • Physiological Measures
     ▪ Heart rate variability, Blood Pressure and Grip Strength
   • Concussion assessment measures
     ▪ Symptoms, Cognition, Balance, Mood, Activity and Sleep
3. To analyze physiological measures post-concussion and compare these to pre-injury baseline measures.
3. Acute Response of Measures

3.1. Introduction

The vast majority of individuals who experience sport-related concussions will likely not have the benefit of pre-injury baseline concussion testing. Although baseline testing is becoming more common there is still a need to be able to assess individuals in the absence of pre-injury comparative tests. Without objective measures clinicians must rely on subjective symptoms, which we know to be unreliable, and have little evidence to base return to activity decisions upon (Lovell et al., 2006). Identifying if post-concussion physiological measures display predictable patterns during recovery may help with identification of concussion and assist return to activity decisions.

3.2. Objectives

We aim to examine the acute response of physiological and routinely used concussion assessment tools following concussion in varsity athletes.

In order to accomplish this research the following objectives were identified;

1. To develop and pilot test a protocol that included physiological and performance measures.

2. To examine the response of physiological and performance (HRV, grip & BP) immediately following concussion.

3.3. Methods and Procedure

3.3.1. Design

This research was conducted using a prospective, longitudinal design. Analysis of 10 cases was used to examine physiological and performance measures following sport-related concussion.
3.3.2. Participants

Healthy, varsity athletes who were able to understand, communicate in English and provide informed consent were eligible to participate in this study. Inclusion criteria were assessed through self-report on a demographic questionnaire. Appendix 2 contains the demographic questionnaire.

Participants were excluded if they had; heart or cardiovascular disease, prescribed medication that influenced heart rate or blood pressure, medical conditions that altered heart rate or blood pressure or a history of psychiatric disease or mental health conditions.

Participants were recruited from Ryerson University’s men’s and women’s varsity teams (hockey, soccer, basketball, volleyball). Seventy-nine athletes were baseline tested during year one of the study and four participants experienced a sport-related concussion. During year two of data collection, ninety-five athletes were baseline tested and six participants experienced a sport related concussion.

Ten athletes were included in this study. Athletes were between the ages of 17-25 years old (M=19.8 years, SD = 2.1) at the time of testing. Table 3-1 provides descriptive information for all participants. Of the 10 participants included in this study, 3 had no previous history of concussion and 7 had a history of 1 or more diagnosed concussions. All participants provided informed consent as approved by Ryerson University’s Research Ethics Review Board. Appendix 3 contains the informed consent documents.
Table 3-1 Demographic Characteristics

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Sport</th>
<th>Previous Concussions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>Soccer</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>19</td>
<td>Soccer</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>19</td>
<td>Volleyball</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>Hockey</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>Hockey</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>17</td>
<td>Hockey</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>Basketball</td>
<td>2</td>
</tr>
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<td>20</td>
<td>Basketball</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>21</td>
<td>Volleyball</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>Hockey</td>
<td>0</td>
</tr>
</tbody>
</table>

3.3.3. Outcome Measures

*Heart Rate Variability*

Heart rate variability was used to assess autonomic function and cerebral autoregulation (Kamath et al., 2012). Heart rate variability (HRV) was calculated from heart rate recording. Heart rate recording was obtained from a Polar RS800CX watch and chest strap. Kubios HRV (University of Kuopio, Finland 2.1) was used to obtain frequency domain measures of HRV. Measurements of HRV obtained at rest display significantly higher reliability than those involving positional or pharmacological interventions (Sandercock, Bromley & Brodie, 2005). However, it is clear from the literature that HRV measures in clinical populations display poorer reliability than those obtained from healthy subjects (Pinna et al., 2007). Validity and reliability of HRV measures differ significantly depending on time versus frequency domain measures, length of recording, collection protocol and type of equipment used (Keren et al., 2005). This study focused on collection of frequency domain measures. Marks and Lightfoot (1999) found correlation coefficients of frequency domain measures collected during 5 min of supine rest to range from 0.67 to 0.96.
**Blood Pressure**

Blood pressure was collected as a measure to assess blood flow and systemic circulation. Blood pressure was collected on the left arm according to the Canadian Hypertension Education Program guidelines (Myers, McInnis, Fodor, Leenen, 2008). BpTRU™ vital signs monitor (model number BPM-100), an oscillometric sphygmomanometer device, was used. Blood pressure via automated sphygmomanometer is a recently developed technology that is intended to reduce “white coat” effects on patients (Myers, McInnis, Fodor, Leenen 2008). Although the automated systems generally are slightly less precise than manual sphygmomanometer readings its use in clinical settings for individuals with normal blood pressure has been validated (Skirton, Chamberlain, Lawson, Ryan & Young, 2011). Reasonably good correlations were found with both systolic pressure 0.85, and diastolic pressure 0.7 (Gupta et al., 2009)

**Grip Strength**

Grip strength was tested as an objective measurement of total body strength (Horowitz, Tollin & Cassidy, 1997). The dynamometer provides a measure of peak force exerted in a voluntary contraction of the hand. Bilateral grip strength was assessed using a Baseline Evaluation Instruments: Smedley digital hand dynamometer (model 12-0286) which is recognized as a standard measurement tool for grip assessment. The reliability and validity of grip strength measures is increased by specificity of testing protocol, grip and elbow position. Participants were seated with the shoulder adducted, neutrally rotated, elbow flexed to 90º, forearm in neutral position which has been shown to obtain more reliable grip readings (Mathiowetz, 1984). Participants were instructed to “squeeze as hard as you can, harder, relax.” Intraclass correlation coefficients of peak force has been found to be 0.946 and 0.932 for left and right grip respectively (Niebuhr, Marion & Fike, 1994). Grip strength was selected for its utility to estimate total body strength while minimizing physical demand on recently concussed participants (Reed, Taha & Keightley 2012).
3.3.4. Procedure and Data Collection

All tests were administered by the primary author and lasted approximately 30 minutes.

Participants were tested following sport related concussion an average 3.6 times (range 3-5, SD =0.7) with the first test conducted an average 3 days following injury (range 1-11 days, SD=2.8). Final testing was conducted a mean 14 days following injury (range 3-29 days, SD=9).

Concussion was identified by a certified athletic therapist and diagnosed by a sport medicine physician according to the Zurich concussion guidelines. These guidelines suggest that concussion should be suspected if any symptoms, physical signs, impaired brain function and/or abnormal behaviour are present following direct or indirect force to the head (McCror, 2004). All post-concussion test measures were assessed at rest.

Following recruitment and consent, participants were tested at the Ryerson University Athletic Therapy clinic. Testing was conducted in a quiet office. Participants were equipped with a Polar RS800CX heart rate monitor chest strap and assumed a supine position. Following 10 minutes of quiet rest heart rate data was collected. Heart rate was collected during 5 minutes of supine lying. Blood pressure was assessed in supine rest using a BpTRU™-100 with 5 consecutive automated readings. Grip strength was assessed with 3 trials in both hands starting with the dominant hand. Participants were seated with the shoulder adducted, neutrally rotated, elbow flexed to 90º, forearm in neutral position (Mathiowetz, 1984). Participants were instructed to "squeeze as hard as you can, harder, relax."
<table>
<thead>
<tr>
<th>Measures</th>
<th>Post Injury</th>
<th>Post Injury</th>
<th>Post Injury</th>
<th>Alternate days until recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
<td>Day 2</td>
<td>Day 3</td>
<td></td>
</tr>
<tr>
<td>Heart Rate</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Grip Strength</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

1 Recovery was defined as return of symptoms to baseline or below

3.3.5. Data Analysis

Visual trend analysis was conducted using a descriptive approach to examine post-concussion data. Post-concussion physiological measures were graphed versus time using Microsoft Excel 2010 and visually examined. Visual trend analysis is a technique used in single-subject research to describe outcomes (Gross Portney & Watkins, 2000). This method was selected to provide a general impression of patterns amongst participants to determine if there was consistency within the group of participants. The analysis was chosen to observe if physiological and performance measures could be used to gauge or predict recovery. In this study visual inspection provided a general impression of either an increasing, decreasing, stable or variable pattern. An increasing pattern was defined as post-concussion values that were greater than the initial post-concussion measure. Each post-concussion measure was greater than the previous data point which indicated an upward trend. Decreasing patterns were defined as post-concussion values that were lesser than the initial post-concussion measure. Each post-concussion measure was lesser than the previous data point which indicated a downward trend. Variable patterns were those that showed both and increasing and decreasing trends within the acute phase. A variable pattern was identified if post-concussion measures displayed both an upward and downward trend when
compared to the initial measure. The post-concussion values had to be both greater and less than the initial data point to be considered as a variable pattern. Typically multiple data points are collected during two adjacent phases. Changes in phases are assessed by examining variability, trend and level (Gross Portney & Watkins, 2000; Wolery & Harris, 1982). Visual trend analysis can only make comparisons across adjacent phases (Gross Portney & Watkins, 2000). Assessing single-subject data in this manner has been successfully used in a variety of contexts including education (Ottenbacher, 1990), rehabilitation (Bracciano et al., 2012) and assessment of the validity of quantitative analysis (Wolery & Harris, 1982). Due to the design of this research study visual trend analysis was a method to identify the existence of patterns. Although it is generally used to assess within-phase and between-phase characteristics (Wolery & Harris, 1982) it is used in this context to identify if there are predictable patterns during recovery. Patterns were assessed as increasing, decreasing or stable trends. Although this method is a purely descriptive approach, which is more qualitative in nature, it was intended to determine if this is a suitable method for assessing measures post-concussion. It was utilized to enhance our understanding for the role that baseline testing plays in concussion assessment. Visual trend analysis examines the trend, level and slope of the data. Trend referred to the direction of change within a phase which may be accelerating, decelerating, stable or variable. Level was identified by the magnitude of change between adjacent phases and slope was the angle or rate of change within the data (Gross Portney & Watkins, 2000).

Heart rate variability (HRV) was calculated from heart rate recording. Heart rate information for each participant was uploaded via a USB interface to Polar Pro Trainer 5 software for Windows. Heart rate data was visually assessed for irregularity. Low frequency (LF), high frequency (HF), the ratio of LF:HF and total power are used to reflect HRV. LF is a measure of sympathetic and parasympathetic tone. HF represents parasympathetic tone and LF:HF is used to assess the balance of the sympathetic and parasympathetic control mechanisms. Total power (HRV) reflects the total variance in heart pattern (Kamath et al., 2012). Frequency domain measures were the focus of this study as the two previous studies examining HRV and concussion assessed frequency domain measures as well (LaFountaine et al., 2009; Leddy et al., 2007).
Heart rate data was uploaded into Kubios HRV as an HRM file to obtain frequency domain measures (University of Kuopio, Finland version 2.1). Heart rate frequency was visually assessed in Kubios HRV and a low level artifact correction was applied to all data. Short term sampling obtained a five minute selection for each participant (Sandercock, 2007).

Mean scores were calculated for dominant and non-dominant grip strength scores based on 3 trials. Mean arterial pressure (MAP) was calculated based on an average of 5 blood pressure readings. \( \text{MAP} = \frac{2}{3}(\text{Systolic Pressure}) + \frac{1}{3}(\text{Diastolic Pressure}) \). MAP is used to describe an average blood pressure reading in an individual.

3.4. Results

Raw data are displayed for each of the measures. Analysis in the acute phase following concussion was observed up to ten days post-injury. Participant 9 was excluded from analysis because the first post-concussion measure was obtained on day 11 post injury. Results are displayed in line graphs with time in days post-injury along the x-axis.

3.4.1. Heart Rate Variability Measures

3.4.1.1. High Frequency (HF)

Line graph of the post-concussion HF values over time are displayed in Figure 1. The right hand legend outlines participant codes. Participant identification is coded by their unique number, followed by their gender (F=female, M=male), sport (B = basketball, H= hockey, S = soccer, V=volleyball) and number of previous concussions. For example, 2FS0 is participant number two, female, soccer player with no previous concussions. There were four unique trends identified in HF results post-concussion. The trend that occurred with the highest frequency occurred in 3 participants (2, 7 & 8) who showed increasing levels in the acute post-concussion phase. Two participants (5 & 10) displayed decreasing levels of HF and one participant (3) showed a plateau. Participants 4 and 6 each demonstrated a unique pattern. Both participants exhibited recurrence of symptoms during the return to play phase and participant 4 with the highest variability in the HF measure had not returned to sport one year post injury. Appendix 7 contains r-squared values and trend lines for participants with more than two data points.
3.4.1.2. Low Frequency to High Frequency Ratio (LF:HF)

Visual trend analysis identified four unique patterns post-concussion. Figure 2 displays a line graph of the post-concussion LF:HF values over time. The trend observed with the highest frequency occurred in 3 of 9 participants and demonstrated an increase in LF:HF in the acute phase post-concussion. One participant (2) demonstrated a plateau and two participants (7 & 10) showed decreasing values for LF:HF. Similar to the findings of HF HRV there were two participants who demonstrated a variable pattern post-injury. Participants 4 and 6 both displayed the most unstable LF:HF values. As stated previously both participants experienced prolonged RTP and experienced recurrence of symptoms during the return to activity process. Appendix 8 contains r-squared values and trend lines for participants with more than two data points.
3.4.1.3. Total Power (HRV) vs. Time

Total Power HRV is the sum of VLF + LF + HF (Very low frequency, low frequency and high frequency). Visual trend analysis identified four unique trends. Figure 3 displays a line graph of the post-concussion Total Power values over time. The trend occurring with the highest frequency was observed in 3 of 9 participants and demonstrated a plateau in the acute phase post-concussion. One participant (8) showed an increase in total power and two (participants 3 & 10) showed decreasing total power post-concussion. Participant 4 and 6 again showed a unique and variable pattern post-concussion which demonstrated an initial decrease in total power followed by a plateau. Appendix 9 contains r-squared values and trend lines for participants with more than two data points.
3.4.2. Mean Arterial Pressure

There were three trends observed in the MAP data from this sample. MAP data is displayed in Figure 4. Four out of nine participants displayed either a flat (participants 2, 3, 5 & 7) or decreasing (participants 4, 6, 8 & 10) MAP in the acute phase following concussion. One participant (1) displayed a unique increasing pattern post-concussion. Appendix 10 contains r-squared values and trend lines for participants with more than two data points.
3.4.3. Grip Strength

3.4.3.1. Dominant Grip

Dominant grip strength scores post-concussion are displayed in figure 5. The trend with the highest frequency occurred in 8 out of 9 participants and displayed a flat pattern post-concussion. Participant 1 demonstrated the highest range (6.9 kg) of grip scores in an upward trend with the highest score occurring on day 5 post injury when he self-reported the lowest subjective symptoms. Appendix 11 contains r-squared values and trend lines for participants with more than two data points.
3.4.3.2. Non-Dominant Grip

There were two differing patterns of non-dominant grip strength in this sample. Figure 6 displays post-concussion non-dominant hand grip strength scores over time. The trend with the highest frequency displayed a flat pattern post-concussion in 8 of 9 participants. Similar to dominant grip scores, participant 1 demonstrated the highest range of grip scores in the non-dominant hand (range = 7.3 kg). Appendix 12 contains r-squared values and trend lines for participants with more than two data points.
3.5. Discussion

3.5.1. Summary of Findings and Implications

Physiological and Performance Measures

Of the physiological and performance measures, HRV data displayed the highest levels of variability. Post-concussion data alone did not appear to yield information regarding the presence of concussive injury but may shed light on individuals who are at risk for experiencing a prolonged recovery. Participants 4 and 6 displayed variable, unique trends in contrast to all other participants.

MAP values fell within the expected normative range of 70-100mmHg (Myers et al., 2008). It is worth highlighting the unique response of participant one who demonstrated an increase in MAP values. This participant was the sole male in the sample and had the highest subjective
symptoms post-concussion. Participant one had the highest incidence of 6 previous sport-related concussions. The unique response of this participant may highlight that gender and previous history of concussion could influence the physiological response post-concussion. It has been reported in the literature that there appears to be gender differences in both the incidence of concussion, reporting of symptoms and recovery rates (Dick, 2009).

Grip strength patterns were consistent within participants demonstrating similar bilateral trends. This may indicate that testing both dominant and non-dominant grip may not be necessary when evaluating trends related to grip strength.

3.6. Study Limitations

The current study examined the physiological and performance measure trends in post-concussion participants. Data from this sample of nine participants is a limitation of the study. This homogenous sample consisting of one male and eight female participants is not representative of the population from which it was obtained. As such, a more representative sample would enhance the applicability of findings.

Additional data points for each participant may reveal a more consistent pattern during recovery or highlight the variable nature of an individual response post-concussion. Consistent timing of data collection in the acute phase would allow for a more robust statistical trend analysis in which split-middle trend analysis (Gross Portney & Watkins, 2000) may provide additional useful information. This statistical analysis is designed to demonstrate if data are accelerating, decelerating or stationary by using a best-fit trend line. Its ability to make inference from the sample is greater than that of a basic visual analysis (Gross Portney & Watkins, 2000).

3.7. Conclusion

Results from the visual trend analysis revealed a variety of visual patterns. This sample demonstrated that there may be gender differences in the response of the physiological measures and that the history of concussion may also play a role. The limited sample size prevents from any definite conclusions but do provide direction for further research. For participants who
experienced a prolonged return to play process, it appears there may be increased variability of HRV measures. It is possible that the variability of the measure is in fact a trend.
4. Comparing Physiological Measures pre and post-concussion

4.1. Introduction

Baseline testing has become a hallmark of concussion assessment and incorporates neuropsychological testing, balance testing and subjective symptom scoring. The individual nature of concussion and the unique presentation of symptoms lend itself to the framework of a baseline testing model. In an ideal environment all athletes obtain baseline measures on these tests, and are used as a comparison in the event of injury.

Baseline testing operates under the principle that recovery is achieved when scores on a given test return to their pre-injury, baseline values. In order for this theory to hold true there must be a method to evaluate if a measure has changed from baseline and subsequently returned to baseline upon recovery.

4.2. Objectives

We aim to examine the acute response of physiological parameters following concussion in varsity athletes and compare to pre-injury baseline scores.

In order to accomplish this research the following objective was identified;

**To analyze three physiological and performance measures (HRV, blood pressure & grip strength) and routinely used concussion assessment measures (balance, cognition, symptoms, mood, activity and sleep)**

To our knowledge this is the first study of its kind to conduct *baseline* measures and repeat testing post-concussion on objective measures of autonomic function and cerebral autoregulation.
4.3. Methods and Procedure

4.3.1. Design

This research was conducted using a prospective, longitudinal design. A pre-season baseline testing session was completed and compared to the first post-concussion measure for each participant. Physiological and performance measures (HRV, BP & grip strength) were compared pre and post injury.

4.3.2. Participants

Healthy, varsity athletes who were able to understand and communicate in English and provide informed consent were eligible to participate in this study. Inclusion criteria were assessed through self-report on a questionnaire.

Participants were recruited from Ryerson University’s men’s and women’s varsity teams (hockey, soccer, basketball, volleyball). Seventy-nine athletes and ninety-five athletes were baseline tested during years one and two respectively of the study.

Six participants who sustained a concussion were included in the physiological measures with baseline. They were assessed on all physiological measures at baseline and post-concussion. Of the six participants, one had no previous history of concussion, and five had a history of one or more diagnosed concussions. All participants provided informed consent as approved by Ryerson University’s Research Ethics Review Board.

Participants were between the ages of 19-21 years old (M=20 years, SD = 0.6 years) at the time of testing. Table 3-1 provides demographic characteristics for all participants. Participants were excluded if they had; heart or cardiovascular disease, prescribed medication that influenced heart rate or blood pressure, medical conditions that alter heart rate or blood pressure or a history of psychiatric disease or mental health conditions.
Table 4-1 Demographic Characteristics (Baseline Group)

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Sport</th>
<th>Previous Concussions</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>17</td>
<td>Hockey</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>17</td>
<td>Hockey</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>Basketball</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>Basketball</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>21</td>
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<td>1</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>Hockey</td>
<td>0</td>
</tr>
</tbody>
</table>

4.3.3. Outcome Measures

*Heart Rate Variability*

Heart rate variability was used to assess autonomic function and cerebral autoregulation (Kamath et al., 2012). Heart rate variability (HRV) was calculated from heart rate recording. Heart rate recording was obtained from a Polar RS800CX watch and chest strap. Kubios HRV (University of Kuopio, Finland 2.1) was used to obtain frequency domain measures of HRV. Measurements of HRV obtained at rest display significantly higher reliability than those involving positional or pharmacological interventions (Sandercock, Bromley & Brodie, 2005). However it is clear from the literature that HRV measures in clinical populations display poorer reliability than those obtained from healthy subjects (Pinna et al., 2007). Validity and reliability of HRV measures differ significantly depending on time versus frequency domain measures, length of recording, collection protocol and type of equipment used (Keren et al., 2005). This study focused on collection of frequency domain measures. Marks and Lightfoot (1999) found correlation coefficients of frequency domain measures collected during 5 min of supine rest to range from 0.67 to 0.96. Due to the novelty in HRV collection and its lack of consistent protocols within this population no evidence of meaningful change scores have been identified.

Low frequency (LF), high frequency (HF), the ratio of LF:HF and total power are used to reflect HRV. LF is a measure of sympathetic and parasympathetic tone. HF represents parasympathetic tone and LF:HF is used to assess the balance of the sympathetic and parasympathetic control
mechanisms. Total power (HRV) reflects the total variance in heart pattern (Kamath et al., 2012).

**Blood Pressure**

Blood pressure was collected as a measure to assess blood flow and systemic circulation. Blood pressure was collected on the left arm according to the Canadian Hypertension Education Program guidelines (Myers, McInnis, Fodor, Leenen, 2008). BpTRU™ vital signs monitor (model number BPM-100), an oscillometric sphygmomanometer device, was used. Blood pressure via automated sphygmomanometer is a recently developed technology that is intended to reduce “white coat” effects on patients (Myers, McInnis, Fodor, Leenen 2008). Although the automated systems generally are slightly less precise than manual sphygmomanometer readings its use in clinical settings for individuals with normal blood pressure has been validated (Skirton, Chamberlain, Lawson, Ryan & Young, 2011). Reasonably good correlations were found with both systolic pressure 0.85, and diastolic pressure 0.7 (Gupta et al., 2009)

**Grip Strength**

Grip strength was tested as an objective measurement of total body strength (Horowitz, Tollin & Cassidy, 1997). The dynamometer provides a measure of peak force exerted in a voluntary contraction of the hand. Bilateral grip strength was assessed using a Baseline Evaluation Instruments: Smedley digital hand dynamometer (model 12-0286) which is recognized as a standard measurement tool for grip assessment. The reliability and validity of grip strength measures is increased by specificity of testing protocol, grip and elbow position. Participants were seated with the shoulder adducted, neutrally rotated, elbow flexed to 90º, forearm in neutral position which has been shown to obtain more reliable grip readings (Mathiowetz, 1984). Participants were instructed to “squeeze as hard as you can, harder, relax.” Peak force measures display higher intraclass correlation coefficients (ICC) when compared to slope and sustained contractions. ICC of peak force has been found to be 0.946 and 0.932 for left and right grip respectively (Niebuhr, Marion & Fike, 1994). Grip strength was selected for its utility to estimate
total body strength while minimizing physical demand on recently concussed participants (Reed, Taha & Keightley 2012).

**Sport Concussion Assessment Tool 2 (SCAT2)**

The Sport Concussion Assessment Tool-2, a standardized tool to evaluate injured athletes for concussion is designed for use by medical and health professionals. SCAT-2 includes the post-concussion symptom scale (PCS), physical sign score, Glasgow Coma Scale (GSC), Maddocks score, cognitive assessment score (SAC), balance error scoring system (BESS), and coordination task (McCrorry et al., 2008). The SCAT-2 is a compilation of various previously identified concussion assessment tools. Although reliability and validity of all tools has been identified, the SCAT-2 as a whole has limited evidence based research reporting reliability and validity. Chan and colleagues note that Intraclass Correlation Coefficient (ICC) for the total SCAT-2 score is fair for young adults, 0.367. Although individual components of the SCAT-2 (SAC, GCS, Maddocks score, BESS) showed increased ICC they are still considered low (2013). A systematic review of the BESS reported test-retest reliability ranging from 0.61 to 0.92 (Bell, Guskiewics, Clard and Padua, 2011). Appendix 4 contains the Sport Concussion Assessment Tool-2.

**Profile of Mood States Short Form (POMS-SF)**

The POMS-SF assessment provides a rapid, economical method of assessing transient, fluctuating active mood states (Curran, Andrykowski, & Studts, 1995). It is an ideal instrument for measuring and monitoring change across various settings (Lorr, McNair & Droppleman, 2003). Profile of mood states has been previously used in varsity athletes to examine the emotional sequelae of mTBI (Mainwaring et al., 2004). The original POMS scale with its 65 items may present a challenge to impaired populations, such as post-concussion patients. As such the POMS-SF was used as its psychometric properties exceed that of the original POMS (Curran, Andrykowski & Studts, 1995). The short form has been validated for its ability to accurately determine mood states. Internal consistency of the POMS-SF ranged from 0.8-0.91,
which exceeds that of the original POMS (Curran, Andrykowksi & Studts, 1995). Appendix 5 contains the Profile of Mood States – short form questionnaire.

Activity and Sleep Log

Activity and sleep quality and quantity were recorded using an activity and sleep log. This unique log was created by the author for three reasons;

1. To observe the impact of concussion on activity and sleep.
2. To examine the influence of activity and sleep on recovery.
3. To investigate the role of activity and sleep on physiological measures.

Sleep quality was assessed on a 0-10 likert scale, and quantity of nighttime sleep. Mental, physical and social activity was assessed on a likert scale of 0-10. Activity and Sleep log was added as an amendment in year two of the study. Appendix 6 contains the activity and sleep log.

4.3.4. Procedure and Data Collection

Baseline testing was conducted by Certified Athletic Therapists, trained in the experimental protocol and lasted approximately 30 minutes. All post-concussion testing was administered by the primary author.

Participants who were diagnosed with a concussion were re-tested according to the proposed timeline of data collection as outlined in Table 3-2.

Participants were tested an average 3.6 times (range 3-5, SD =0.7) following injury. Participants were baseline tested an average 76 days prior to injury (range 19-139 days, SD=52 days) with the first test conducted an average 3 days following injury (range 1-11 days, SD=2.8).

Concussion was identified by a certified athletic therapist and diagnosed by a sport medicine physician according to the Zurich concussion guidelines. These guidelines suggest that concussion should be suspected if any symptoms, physical signs, impaired brain function and/or
abnormal behaviour are present following direct or indirect force to the head (McCrory, 2004). All post-concussion test measures were assessed at rest.

Following recruitment and consent, participants were tested at the Ryerson University Athletic Therapy clinic. Testing was conducted in a quiet office. For each testing session the following tests were administered; heart rate, blood pressure, grip strength test. Participants were equipped with a Polar RSX 800 heart rate monitor chest strap and assumed a supine position. Following 10 minutes of quiet rest heart rate data was collected. Heart rate was collected during 5 minutes of supine lying. Blood pressure was assessed in supine rest using a BpTRU™-100 with 5 consecutive automated readings. Grip strength was assessed with 3 trials in both hands starting with the dominant hand. Participants were seated with the shoulder adducted, neutrally rotated, elbow flexed to 90°, forearm in neutral position (Mathiowetz, 1984). Participants were instructed to “squeeze as hard as you can, harder, relax.”
Table 4-2 Proposed Timeline of Data Collection (Baseline Group)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Post Injury</th>
<th>Post Injury</th>
<th>Post Injury</th>
<th>Alternate days until recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
<td>Day 2</td>
<td>Day 3</td>
<td></td>
</tr>
<tr>
<td>Heart Rate</td>
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<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Grip Strength</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SCAT-2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symptom Checklist</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Profile of Mood States - Short Form (POMS-SF)</td>
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<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Activity/Sleep Log</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

1. Activity and Sleep log introduced as an amendment in year two of study
2. Recovery was defined as return of symptoms to baseline or below

4.3.5. Data Analysis

Outcome measures were assessed pre and post-concussion. In order to identify if a physiological measure could be used as an indicator of concussion it would be clinically different than the baseline measure. RCI is typically used to assess clinically meaningful change following an intervention. Its utility in this context is to assess change in physiological measures when comparing baseline and post-concussion measures. Reliable change index (RCI) scores were
calculated for grip strength and heart rate variability scores. A reliable change index above 1.96 is considered statistically significant as this value equates to the 95% confidence interval (Jacobson & Truax, 1991). Reliable change index score is calculated by $\frac{\text{pre score} - \text{post score}}{\text{Standard Difference}}$, the standard difference is obtained by $\sqrt{2(SEM)^2}$. Standard error of measurement (SEM) is the $SD \sqrt{1 - r}$ where SD is the standard deviation and r is the reliability coefficient.

RCI is a statistically useful measure with very small sample sizes (Zahra & Hedge, 2010). The test provides a clinically useful measure when performing a statistical test that is not desired to generalize to a broader population. Test-retest reliability of .946 and .932 were used for left and right grip respectively for reliable change index calculations (Niehbur et al., 1994). Test-retest reliability of .67 and .86 were used for HF and LF:HF respectively for HRV reliable change index calculations (Marks & Lightfoot, 1999).

Reliable change index scores require the use of test-retest reliability to perform the calculation. Based on the available literature a study with similar methods and sample was not available for comparison for blood pressure. Therefore, assessment of blood pressure scores from baseline to post-concussion was analyzed by the Two Standard Deviation band method (Gross Portney & Watkins, 2000). In a normal distribution 95% of the values are contained within two standard deviations. Therefore if a value falls outside two SD’s it can be considered to represent a confidence interval of approximately 95%. The standard error of the mean (SEM) for the sample was used as a proxy for SD for blood pressure measures (Ottenbacher, 1990).

A measure would be considered sensitive to concussion if it were to achieve reliable change. Blood pressure measures that fall outside two SD’s were assessed as clinically different when compared to baseline.

SCAT-2 components of symptoms, GCS, cognitive evaluation (SAC score) and balance examination (BESS score) were examined.
Subscales of POMS-SF including tension, depression, anger, fatigue, confusion, vigor, and total mood disturbance (TMD) were examined.

Activity log subscales of perceived mental and physical activity on a likert scale of 0-10 were analyzed. Sleep log analyzed perceived quality of sleep on a likert scale of 0-10. Hours of mental, physical and social activity as well as hours of sleep were examined.

Descriptive statistics were analyzed for each component of the routinely used concussion assessment measures. A paired samples, two-tailed, t-test was computed to examine the baseline and post-concussion scores on concussion assessment measures. Welch’s t-test was computed to compare group scores with previous history of concussion and those participants without a history of concussion.

- Scatterplot analysis was conducted to examine the relationship between concussion symptoms and physiological and performance measures (HRV, BP & grip),
- POMS-SF (total mood disturbance, vigor, depression & fatigue) and heart rate variability,
- POMS-SF total mood disturbance and blood pressure (systolic, diastolic & MAP)
- Activity/sleep log quality and HRV
- Activity/sleep log quality and BP (systolic, diastolic & MAP)

The above correlations were selected because of the hypothesized relationship between variables. There is evidence from the literature to confirm that physiological measures are influenced by a number of factors (Kamath et al., 2012; Myers, McInnis, Fodor, Leenen 2008). Heart rate variability responds to internal and external stimuli which are a reflection of the autonomic nervous system. The ANS responds to internal stimuli like breathing rate, blood pressure, mood and external stimuli like activity and environment. Decreased HRV is seen when the ANS is impaired and is experiencing difficulty responding and adapting to environmental changes.
(Kamath et al., 2012). Examination of these relationships is essential to rule out confounding variables that may influence HRV. Scatterplot analysis that revealed a visual positive or negative relationship were further analyzed by calculating the correlation coefficient between the two variables.

4.4. Results

4.4.1. Heart Rate Variability

Reliable change index scores for HF and the ratio of low frequency to high frequency (LF:HF) of heart rate variability scores are listed in table 3-4. Reliable change was observed in one participant for both HRV measures.

It should be noted that underlined scores are identified as outside expected normative values for HRV as outlined by the Task Force of the European Society of Cardiology (1996). Appendix 13 contains normative HRV data.

Scatterplot analysis did not reveal any visual relationship or subsequent significant correlations between any HRV measures and concussion symptoms, mood, activity or sleep. See appendix 14 for HRV scatterplots.

<table>
<thead>
<tr>
<th>Participant #</th>
<th>Average HR Baseline</th>
<th>HF</th>
<th>LF:HF</th>
<th>RCI</th>
<th>Post- Injury 1 Baseline</th>
<th>Post-Injury 1</th>
<th>HRV</th>
<th>LF:HF</th>
</tr>
</thead>
<tbody>
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<td>67.59</td>
<td>3299</td>
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<td>71.69</td>
<td>63.22</td>
<td>530</td>
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<td>-0.162</td>
<td>0.511</td>
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<tr>
<td>8</td>
<td>55.95</td>
<td>55.12</td>
<td>928</td>
<td>213</td>
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<td>0.684</td>
<td>-0.81</td>
<td>-0.111</td>
</tr>
<tr>
<td>9</td>
<td>69.12</td>
<td>73.44</td>
<td>904</td>
<td>134</td>
<td>1.300</td>
<td>1.907</td>
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<td>1.722</td>
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<tr>
<td>10</td>
<td>86.05</td>
<td>57.48</td>
<td>259</td>
<td>2315</td>
<td>1.983</td>
<td>1.175</td>
<td>2.33</td>
<td>-2.293</td>
</tr>
</tbody>
</table>

RCI = Reliable Change Index
4.4.2. Blood Pressure

Blood pressure scores are indicated in Table 3-5. Standard error of the mean (SEM) for systolic and diastolic blood pressure was calculated for the baseline group sample as 4.5 and 3.6 respectively. In order to obtain clinical significance for systolic or diastolic blood pressure a difference of at least 9 mmHg and 7.2 mmHg respectively would be required. As no participant showed this level of change from baseline to post-injury measure one it shows that there was no significant difference in blood pressure for this sample. Scatterplot analysis did not reveal any visual relationship or subsequent significant correlations between any blood pressure measures and concussion symptoms, mood, activity or sleep.

Table 4-4 Blood Pressure Raw Data (Baseline – 1st measure)

<table>
<thead>
<tr>
<th>Participant #</th>
<th>Blood Pressure</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Post-Injury</td>
<td>Baseline</td>
<td>Post-Injury</td>
<td>Systolic</td>
<td>Diastolic</td>
<td>Difference</td>
</tr>
<tr>
<td>5</td>
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<td>127</td>
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<td>82</td>
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<td>-1</td>
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</tr>
<tr>
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<td>86</td>
<td>87</td>
<td>63</td>
<td>60</td>
<td>-1</td>
<td>3</td>
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</tr>
<tr>
<td>7</td>
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<td>101</td>
<td>62</td>
<td>66</td>
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<td>-4</td>
<td></td>
</tr>
<tr>
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<td>66</td>
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<td>10</td>
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<td>78</td>
<td>75</td>
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<td></td>
</tr>
</tbody>
</table>

Standard Error of the Mean 4.5 3.6

4.4.3. Grip Strength

RCI scores for dominant and non-dominant grip strength scores are listed in table 3-3. Scores that achieved reliable change are in bold font. Reliable change was observed in one dominant grip strength score for participant 5 which demonstrated an increase in grip strength following concussion. Four scores achieved reliable change in the non-dominant grip (Participants 5, 7, 8 & 9). Participants 7 and 8 showed decreased grip strength and participants 5 and 9 demonstrated an increase in grip strength. Scatterplot analysis did not reveal any visual relationship or subsequent significant correlations between any grip strength scores and concussion symptoms.
Table 4-5 Grip Strength Reliable Change Index Scores (Baseline – 1st measure)

<table>
<thead>
<tr>
<th>Participant #</th>
<th>Baseline</th>
<th>Post-</th>
<th>Baseline</th>
<th>Post-</th>
<th>Dominant RCI</th>
<th>Non-Dominant RCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>36.4</td>
<td>40.3</td>
<td>32.6</td>
<td>35.6</td>
<td>2.403</td>
<td>2.047</td>
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<tr>
<td>6</td>
<td>33.5</td>
<td>32.1</td>
<td>28.3</td>
<td>30.7</td>
<td>-0.863</td>
<td>0.75</td>
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<td>7</td>
<td>27.7</td>
<td>29.4</td>
<td>30.2</td>
<td>27.1</td>
<td>1.048</td>
<td>-2.183</td>
</tr>
<tr>
<td>8</td>
<td>41.7</td>
<td>41.1</td>
<td>39.6</td>
<td>36.4</td>
<td>-0.37</td>
<td>-2.183</td>
</tr>
<tr>
<td>9</td>
<td>34.2</td>
<td>31.2</td>
<td>26.1</td>
<td>29.3</td>
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<tr>
<td>10</td>
<td>30.7</td>
<td>31.8</td>
<td>27.4</td>
<td>26.1</td>
<td>0.678</td>
<td>-0.546</td>
</tr>
</tbody>
</table>

RCI = Reliable Change Index

4.4.4. Sport Concussion Assessment Tool-2 (SCAT-2)

Post-Concussion Symptom Scale (PCS)

Symptom scores for all participants are listed in table 4-6. Raw data for all SCAT-2 measures are listed in table 3-4. Our results show a range of PCS scores of 0-78. Participant 1, who was the sole male in the group and had the highest number of previous concussions, displayed the highest post-concussion symptom scores ($M = 78$). Symptom scores in this study display a downward trend during recovery. We do however find that some participants do not show decreases in PCS every day. In most cases we see that post-injury PCS scores are above the level of baseline, indicating a worse subjective condition than baseline. We find that baseline ($M = 6.3$, $SD = 4.06$) symptom scores were less than post-injury ($M = 20.6$, $SD = 21.58$) symptom scores; $t(10) = .05$, $p = 0.49$. We did observe that 3 of 9 participants exhibited post-concussion scores below baseline (Participants 2, 3 and 5). Participants with no previous history of concussion reported lower symptom severity at baseline ($M = 4$, $SD = 2.82$) compared to those with a history of one or more concussions ($M = 7$, $SD = 4.17$); $t (10) = .04$, $p = 0.48$
### Table 4-6 Post-Concussion Symptom Scale

<table>
<thead>
<tr>
<th>#</th>
<th>ID</th>
<th>Time</th>
<th>PCS /132</th>
</tr>
</thead>
<tbody>
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<td>1MS6</td>
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<td>5</td>
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<tr>
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<td></td>
<td>0</td>
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Glasgow Coma Scale (GCS)

GCS scores for all participants at baseline and post-concussion was 15/15. This indicates that all participants displayed the best eye, motor and verbal response scores. GCS scores rule out that any participant suffered a moderate TBI.

Cognitive Evaluation (SAC score)

Cognitive scores, out of a possible 30 points, were calculated as the sum of the orientation, immediate memory, concentration, and delayed recall scores. Our findings indicate that participants with no history of concussion (n=3) achieved higher mean cognitive scores (29/30) when compared to participants with a history of one or more diagnosed concussions (n=6) (25.2/30) at the time of baseline; $t(9) = 0.02, p = 0.49$.

Balance Examination (BESS)

Balance scores, out of 30, were calculated using the BESS test during 3 stance conditions. Similar to the cognitive evaluation we see that participants with no history of concussion show greater baseline balance scores (mean = 27.7) compared to those participants with a history of concussion (mean balance = 25.5); $t(9) = 0.59, p = 0.28$. 

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4.4.5. Profile of Mood States – Short Form (POMS-SF)

Profile of Mood States (short form) shows a downward trend of total mood disturbance (TMD) post-concussion through recovery. Of the 4 participants who had both baseline and post-
conclusion data the mean TMD at baseline ($M = -.25, SD = 7.9$) was lower than post-injury scores ($M = 11.25, SD = 16.6$); $t (4) = 0.05, p = 0.48$.

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4.4.6. Activity and Sleep Log

The activity and sleep logs were introduced as an amendment in year two of the study to examine how activity and sleep levels impact recovery. Therefore, participants from year one do not have activity and sleep log data.

Participant 5 self-reported high mental activity in the acute phase without any subsequent repercussions to symptom severity or length of recovery. Participant 5 also displayed a post-concussion symptom score (PCS=3) below the level of her baseline symptom score (PCS=14).

Participants 4 and 6 reported high mental activity (8/10) in the acute phase of injury (days 1-3 post-concussion). These student athletes reported engaging in reading, writing and studying within 1-2 days of injury. Students logged between 3-5 hours of work during this period and reported the mental activity intensity as 8/10. Despite both participants 4 and 6 reporting being asymptomatic at day 6 and day 7 respectively, recurrence of symptoms occurred during the return to play protocol. Participant 6 returned to play approximately 2 months post injury, participant 4 continued to experience post-concussion symptoms 1 year post injury.
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4.5. Discussion

4.5.1. Summary of Findings and Implications

*Heart Rate Variability*
Our results show that 3 out of 4 participants (6, 7 & 8) displayed decreased high frequency (HF) HRV following concussive injury. The only participant (10) to achieve reliable change in HF HRV displayed an increase in HF score. It should be noted that participants who demonstrated a decrease in HF were tested day 1 post injury. Participant 10, who demonstrated an increase in HF, was tested at day 3 post injury. It appears that decreased HF may be an acute response that occurs in days 1 and 2 post injury which may no longer be evident at day 3 post-injury in some cases.

**Blood Pressure**

Blood pressure measurements showed relative stability from a statistical perspective using the two SD band method. There were no scores that achieved a statistically significant difference from this sample. Of the 5 participants we find two participants (5 & 7) demonstrated increased systolic pressures post-concussion. The remaining 3 participants (6, 8 & 10) all showed decreased systolic pressure. Similar results were found for diastolic pressure. Two participants (6 & 10) demonstrated increased diastolic pressure and the remaining three participants (5, 7 & 8) showed decreased diastolic pressure.

**Grip**

Participant 5 was the sole participant who demonstrated increased grip strength scores bilaterally. Of the two remaining scores that achieved reliable change (Participants 7 & 8) both showed a decrease in grip strength in the non-dominant hand. We see that non-dominant grip strength scores display either a decrease in grip strength (3 of 4 participants) or remain the same (1 of 4 participants). The majority of scores in this sample did not reach the level of statistical significance, however these findings may be considered clinically meaningful when addressing return to activity decisions.

**Concussion Assessment Measures**

**Sport Concussion Assessment Tool-2**

There were three findings of interest regarding the symptom scores in this study;
1. Participants with a history of concussion displayed higher baseline scores than those participants with no previous concussion.

2. 3 out of 9 participants displayed post-concussion symptoms scores that were higher than the level of baseline.

3. The participant with the highest number of previous concussion displayed the highest post-concussion symptom severity.

Our findings may suggest that individuals with previous concussion experience more concussion like symptoms at baseline. Although symptom severity is sometimes equated with severity of injury, our findings indicate otherwise. Participant 1 with a history of 6 previous concussions and the highest PCS score, of 78, on the day of injury had an average recovery.

Cognitive results were similar to symptoms in that history of previous concussion resulted in lower mean scores than those with no history of concussion. Of greater interest to the cognitive testing, from an assessment perspective, is that the average post-concussion scores (mean = 27.1) were above the level of baseline (mean = 26.4). This indicates that participants achieved higher scores post-concussion than when they completed their pre-injury baseline.

Balance scores, as assessed by the BESS test, show those participants with no history of concussion display higher baseline scores than those with a history of previous concussion. We find that mean post-concussion balance scores (mean = 27.8) were higher than baseline (mean = 26.2). Participants demonstrated higher balance scores post-concussion which contradicts expected findings. We acknowledge that practice effects and motivation to perform may be factors associated with improved post-concussion scores. Participant 1 was unique in that he demonstrated the poorest balance scores at baseline which may indicate that history of concussion may have long term consequences regarding static balance.

Previous research using the POMS-SF in varsity athletes found total mood disturbance (TMD) to be greater following concussion when compared to both non-injured controls and musculoskeletal controls (Mainwaring et al., 2004). Our findings on TMD were similar in that
post-concussion scores were higher than baseline. This indicates a greater TMD post-concussion. This indicates increased feelings of fatigue, confusion, tension and anger when compared to baseline.

When considering the activity scores of participants 4 and 6 it is possible that high mental activity in the acute phase may have had a negative impact on recovery. It is evident from the literature that physical activity in the acute phase has detrimental immediate and long term consequences (Asplund et al., 2004; Bazarian et al., 2009). As such, a more focused approach to limiting mental activity for student athletes, especially in the acute phase, warrants further examination.

4.6. Study Limitations

The current study is a small sample of female participants which limits the conclusions that can be drawn from the data that has been collected. Results from this homogenous group may not be applicable to males of this age group and may show differing results from baseline to post-concussion.

Single measure comparisons provide limited use for statistical analysis and as such multiple measures of both baseline and post-concussion measures may help to reveal an effect if there is one to be observed.

Several HRV measures that were obtained at baseline and post-concussion were outside the normative values as identified by the Task Force of the European Society of Cardiology (1996). This could indicate an error in data collection or that this sample of participants does not display values consistent with normative values.

4.7. Conclusion

The objective of this research was to analyze three physiological measures (HRV, blood pressure & grip strength) post-concussion and compare these to pre-injury baseline measures. We were able to develop and test a pilot protocol to assess physiological measures following concussion.
It is clear from the literature that decreased HF measures of HRV are associated with poorer outcomes (Kamath et al., 2012). In severe brain injury, HRV measures have been shown to be chronically decreased (Goldstein et al., 1998). Similarly, patients admitted to intensive care units show impaired HRV measures as early as 12 hours, which has been used as a predictor of outcome (Norris, Morris, Ozdas, Grogran & Williams, 2005). From this pilot data set we see that HF HRV may be a sensitive measure in the initial days following concussion. If this is a consistent finding HF HRV could be considered as a tool to assist with identification and assessment. Despite a lack of statistically significant differences between pre and post-conscious scores it is plausible that decreased post-conscious HF and total power measures may assist with assessment and management decisions if this is a consistent finding.

Blood pressure analysis revealed consistency of systolic and diastolic measures when compared to pre-injury baseline. Findings from the literature indicate that blood pressure readings are influenced in moderate and severe brain injury (Shutter & Narayan, 2008). We do not find this to be a consistent finding in more mild forms of brain injury, like those included in this study. From this data we identify that female varsity athletes in this sample display lower blood pressure scores when compared to the general population (Myers, McInnis, Fodor, Leenen 2008). Our findings suggest that blood pressure is a relatively stable measure within this population and that measures can be expected to be similar to baseline following concussive injury.

Grip strength results indicate that non-dominant grip scores may show impairments in some individuals compared to pre-injury baseline scores. From a clinical standpoint there can be repercussions to returning athletes to sport with strength impairments. It is not clear from the literature if post-conscious motor function impairments are chronic in nature and as such should be addressed during rehabilitation. As with other injuries that cause strength impairments, a systematic approach to improve strength is implemented into rehabilitation protocols. A more robust rehabilitation plan to include a motor function component may be warranted.

Inconsistencies were observed in the SCAT-2 data. Scores for both cognition and balance displayed better performance during the post-conscious phase when compared to baseline
scores. Activity log findings suggest that acute mental activity may have a negative impact on recovery.

5. Embedded Case Series Analysis

Due to the pilot nature of this study and the unique response of individuals following concussion a case analysis was conducted. Participants were grouped according to their recovery from concussion and return activity. The average recovery time quoted in the literature for the majority (80-85%) of individuals is 7-10 days (McCrory et al., 2012). For the purpose of this analysis average recovery will be defined as beginning the return to play protocol within 15 days of injury. Participants who recovered faster than this time frame were considered to have an above average recovery. Participants who recovered slower than this time frame were considered to experience a prolonged recovery. One participant (4) was diagnosed with post-concussion syndrome and at 1 year post-injury was still experiencing symptoms. Participant 9 was excluded due to lack of data in the acute phase.

Recovery Groups

5.1.1. Above Average

Participants 3 and 5 reported being asymptomatic 4 days post injury and began the return to play protocol on day 5. Although symptoms are commonly used as a benchmark to assess readiness to begin the return to play protocol its utility is compromised when post-concussion scores are below the level of baseline. Both participants reported that when they were not injured they had more symptoms than after they were diagnosed with a concussion. This data clearly identifies that relying solely on symptoms presents a challenge to clinicians when assessing concussion and readiness for activity.

When taking into consideration the various measures assessed in this study there are several factors that lead to the conclusion that neither participants sustained a concussion. When reviewing the physiological parameters we find that all measures either increased or stayed the same through recovery. The activity log and POMS-SF data identify important information.
Both participants 3 and 5 had high vigor scores (15/24 and 14/24) on the POMS-SF on days 2 and 3 respectively which indicates feeling lively, active, energetic, cheerful and full of pep. These vigor scores highly contrast all other participants during this acute phase post-injury. The range of vigor scores for all other female participants on days 1-3 post injury was 1-5. These feelings of vigor are not common to individuals post-concussion and as such questions the usefulness of current guidelines in assessing concussion. Both participants also achieved low scores on the fatigue subscale which is a common symptom following concussion. Individuals post-concussion often report feelings of tiredness, fatigue and lethargy (Lovell et al., 2006). Participant 5 reported high levels of mental activity without any subsequent repercussions. It is clear from the literature that activity in the acute phase can lead to increase in symptoms (McCrorry & Berkovic, 1998) or delayed recovery (Asplund et al., 2004), neither of which occurred for participant 5. Given that both participants demonstrated contradictory activity and mood symptoms following concussion it is possible that neither participant suffered a concussive injury.

5.1.2. Average

Five participants in this study recovered in what is considered to be an average length according to the literature (McCrorry et al., 2013). Participants 1, 2, 7, 8 and 10 recovered from symptoms and began the return to play protocol within 15 days. The most striking feature of this group is the high level of variability when we examine the data as a whole. Unlike the above average and prolonged recovery we find there to be very few similarities amongst this group. Two participants (2 and 10) in this group had no previous history of concussion. The remaining participants (1, 7 and 8) had a history of 6, 2 and 2 previous concussions respectively. This group is comprised of one male and 4 female athletes participating in soccer, basketball and volleyball.

There were no physiological or standard concussion assessment tools with a similar response, nor were any similarities noted in the subgroups according to history of concussion. Within this group we find that some measures increased, decreased or stayed the same throughout recovery. This finding is one of the most troublesome details of concussion assessment and management.
This group represents the vast majority of individuals who sustain concussion and despite the size of this sample we find no similar findings even on the most commonly used concussion assessment tool, the SCAT-2.

5.1.3. Prolonged

Two participants (4 and 6) experienced a prolonged recovery. Both exhibited recurrence of symptoms during the return to play protocol. Participant 4 was diagnosed with post-concussion syndrome and had not returned to her previous level of activity one year post-injury. Participant 4 experienced a concussion 3 months prior to the concussion reported in this study which may have been a contributing factor in her prolonged recovery. Participant 6 returned to play approximately 2 months post injury. Taking into consideration the data from this study we find some common characteristics between these participants and some differences that exist when compared to the group of participants who experienced no concussion or an average recovery. One of the purposes of this analysis is to identify if there are markers that may predict poor outcome or identify individuals who may be more prone to concussion and prolonged recovery.

Symptom severity has been used in the past to determine severity of injury. Despite prolonged recovery, neither participant reported high levels of symptom severity (Participant 4 max score PCS=17/132, Participant 6 max score PCS=35/132). This reinforces the fact that symptom severity is not a good predictor of outcome and reliance on its use in assessment and management should be minimal. We know from the literature that athletes with a history of concussion are more at risk to experience a subsequent concussion (Boake et al., 2006). Both participants had a history of prior concussion.

POMS-SF data appeared to be sensitive to the severity of injury when compared to participants who experienced an above average recovery. We find participants 4 and 6 with prolonged recovery had high levels of fatigue (11 and 14/20) and low levels of vigor (0 and 3/24). Both showed levels of TMD that were approximately two times the average mood disturbance as reported in the above average and average group in the first 2 days following injury.
HRV scores indicate a highly erratic pattern post-concussion of LF:HF when compared to all other participants. There is a lack of literature available to identify if highly variable patterns of HRV measures are indicative of poor homeostatic control or an indicator of poor outcome.

Blood pressure measures for both participants fall within normative values for this population (Myers et al., 2008). We do however identify that both participants exhibit MAP scores on the low end of the scale in comparison to the general population.

The finding of most significance among these two participants is the self-report of high mental activity on days 2-3 post injury. Participants reported studying, reading and writing in this period which they perceived as mental activity at an intensity level of 8/10. We know from the literature that physical activity within the acute phase can result in long term consequences (Asplund et al., 2004). Findings from this study indicate that high mental activity within the acute phase may also lead to prolonged recovery. This is an important finding when managing the activity levels of student athletes.

Case analysis of groups divided according to recovery highlighted those participants at either end of the extreme show similar findings on post-concussion measures. Those individuals who did not sustain a concussion and those that were clearly concussed and experienced prolonged recovery had similar results. We identify a large group of individuals in the average recovery group who highlight a unique and individual response to concussion. This confirms the need for more sensitive concussion assessment tools as this group likely represents the majority of athletes who could be at increased risk if not properly identified. Lastly, the influence of mental activity in the acute phase may lead to recurrence of symptoms during the return to play protocol and prolonged return to activity. We find that no single measure on its own provided conclusive evidence regarding the assessment of concussion. However the multi-faceted approach of this study revealed clinically relevant information.
6. General Discussion

The overall purpose of this pilot study was to implement a procedure to examine the acute response of select physiological measures and commonly used concussion assessment tools following injury. To our knowledge this is the first study of its kind to conduct baseline measures and repeat testing post-concussion on objective measures of autonomic function and cerebral autoregulation.

Given that this is a novel approach to concussion research our first objective was to develop and test a protocol to include objective, physiological measures (HRV, BP, grip strength). Measures were selected that would be ideal measures for the average clinician which are ecologically valid, rapidly utilized and analyzed with standardized procedures. Our second objective was to use this data to examine pre and post-concussion scores as a means of assessing their utility in clinical assessment of sport-related concussion.

Due to a lack of objective, sensitive measures to assess concussion the need for such a tool is required (Asplund, McKeag & Olsen, 2004; Aubry et al., 2002; Gagnon et al., 2009; Lovell et al., 2006). These measures are necessary as the lack of reliable assessment measures can put athletes at increased risk of injury if an accurate diagnosis is not made. Furthermore, management approaches would be enhanced with objective markers of concussion and recovery.

6.1. Physiological Measures

This study attempted to identify if commonly used physiological measures contributed to the assessment of sport-related concussion. Underreporting and a lack of adequate diagnostic tools hinder the consistent assessment of sport-related concussion. We developed a protocol to assess measures of HRV, blood pressure and grip strength before and after concussion to assess the physiological response of these measures. These data were analyzed in the context of the existence of a baseline and without. Research has demonstrated that various physiological and performance measures have been identified to be impaired in the acute, sub-acute and post-
recovery phases following concussion (LaFountaine et al., 2009; Parker, Osternig, van Donkelaar & Chou, 2007). This data has typically compared injured participants with matched controls. It is important to identify when these impairments occur and assess how they may impact clinical management and recovery.

Heart Rate Variability

The study of HRV is in its infancy as it relates to concussion assessment. There is clarity in the challenges of using HRV as a diagnostic tool and we find evidence that both supports and refutes our findings. Although we found 3 out of 4 participants who experienced decreased HRV measures day 1 post-concussion, research by Gall and colleagues (2004) and LaFountaine et al., (2009) found no change in resting HRV values compared to control groups. Our research differs from the above studies in that there was no control group used. A pre-injury baseline was used as a means of comparison which may explain the lack of consistency in the HRV findings.

The results of this study obtained normative baseline values of frequency domain measures for 98 varsity athletes. We see that HRV normative values are highly variable and many studies reported high SD’s of both time and frequency domain measures (LaFountaine, 2009; Hilz et al., 2011). This evidence of values outside of expected normative data was found in virtually every study that examined the use of HRV and TBI (LaFountaine, 2009; Hilz et al., 2011). As our study identified several measures outside of normative values we see that this appears to be a common trend in the analysis of HRV. These differences may be explained by difference in collection methods (ECG vs HR monitor), populations (young vs old, healthy vs clinical), collection protocols (standing, supine, forced respiration) and time of collection. HRV measures are influenced by many factors. One of the challenges with comparing normative data from various studies is the variability between studies in data collection protocol, equipment and values. The Taskforce of the European Society of Cardiology provide normative data for several heart rate variability measures (1996). This data is not ideal for interpreting the HRV values collected in this study due to a paucity of information regarding the methodology of the studies presented by the taskforce. When comparing the norms from this study to that of Hilz and colleagues (2011), there is less of a discrepancy between the standard deviations and a higher
degree of variability which is consistent with our findings. In light of the discrepancies identified between our normative data and those from the taskforce, and other concussion studies, there is a definite need to establish norms for this population. Although our study did not document the use of pain medication, caffeine or other supplement intake, this information could help to reduce confounding variables associated with heart rate variability.

Although the use of portable HRV devices, like watch heart rate monitors, has been questioned as a tool for use in scientific inquiry it has been found to obtain reliable readings from short term recordings which are in agreement with that of an ECG recording (Grossi Porto & Junqueira, 2009). HRV is a sensitive measure and the literature has identified a variety of factors which can alter it (Keren et al., 2005; Katz-Leurer et al., 2010). Our statistical analysis identified no statistically significant change from baseline to post-injury. Reliable change index calculations require the use of the SD of the sample. As previously stated, the variability of HRV measures in this study and those of Hilz et al., (2011) and LaFountaine et al., (2009) all revealed high SD’s. The variant nature of this measure will impact the RCI calculation requiring very large differences in pre and post injury scores to achieve reliable change. A measure that is not so inherently variable would require a smaller change from pre to post to achieve a statistically significant change score. This enhances the clinical significance of the reduced HRV day 1 post injury compared to baseline scores. Reliable change index was one of the few statistical tests that could be conducted with this data set to examine change scores of the physiological measures.

We identify some challenges associated with the RCI statistic as it relates to a measure like heart rate variability which is variant by nature. The use of the RCI was an effort to enhance the inquiry through a mixed-methods approach, beyond that of the descriptive visual trend analysis.

Grip Strength

Examining the impact of concussion on the neuromuscular system is a challenge in the post-concussion population. Although there are motor tasks involved in a neurocognitive exam the inclusion of a strength task shows a paucity of data. Of the few available studies it has been shown that grip strength was impaired up to 1 month following head injury when compared to matched controls (Haaland et al., 1994). Although our data suggests either a slight decrease or
plateau of grip following concussion, non-dominant grip displayed greater decreases post-injury when compared to pre-injury baseline scores. This finding may suggest that handedness plays a role in recovery of strength post-concussion. Literature from the post-stroke population posits that handedness plays a role in recovery of strength and motor function post-stroke (Sainburd & Duff, 2006). Research examining the effect of handedness on motor execution did not yield significant results in the TBI population (DeBeaumont et al., 2011). The difference between motor tasks requiring strength and those requiring more complex coordination appear to respond differently based on type of brain injury.

We identify that increased grip scores may be the result of time between baseline and re-test as well as a practice effect. While scores are not shown to be impacted by practice effects within an individual testing session (Mathiowetz, 1990), fatigue could have reduced the mean grip scores. Data from this study revealed that participant 1 who displayed the highest range in grip scores also showed the greatest severity of symptoms and high fatigue scores as measured by the POMS-SF.

Blood Pressure

Blood pressure has been used as a common diagnostic tool in the moderate and severe TBI populations (Mitchell, Gregson, Piper, Citerio, Mendelow & Chambers, 2007). There is limited research on the impact of blood pressure post-concussion. Our findings suggest that both systolic and diastolic pressures remain relatively stable when comparing baseline and post-concussion measures. We find there to be no statistically significant difference in these measures using the two SD band method. We did find a greater tendency of the systolic pressure to be decreased compared to diastolic pressure. Shutter and Narayan (2008) found that significantly reduced systolic blood pressure was a strong predictor of outcome in the severely brain injured population. This may indicate that systolic pressure is more sensitive to the impact of brain injury and significant changes may indicate a more severe form of injury. Findings from moderate and severe TBI, requiring hospitalization in intensive care units, identify hypotensive blood pressure readings as a predictor of mortality (Brenner, Stein, Hu, Aarabi, Sheth & Scalea, 2012). One of the challenges of comparing our results to those in moderate and severe TBI,
aside from the obvious difference in severity of injury, is that blood pressure readings were obtained via different equipment. Our study used oscillometric, non-invasive readings whereas intensive care studies frequently use invasive blood pressure readings via the radial artery. Invasive methods have been known to produce more accurate blood pressure readings whereas non-invasive methods typically produce readings approximately 10% lower (Fahda et al., 2011).

Despite the breadth of evidence in the TBI populations regarding blood pressure there still exists contradictory evidence. Mitchell and colleagues identified normal blood pressure readings in their populations of TBI patients (GCS range 3-15). Despite a lack of a normally distributed range, blood pressure readings were within normal limits but skewed toward higher values (2007). These differences may be explained by the broad range of patients in the Mitchell study, including mild, moderate and severe TBI’s. The inclusion of various severities could have influenced the distribution of blood pressure readings in this study.

Our findings are more in line with those of Loizou and colleagues who identified relative stability following injury (2010). It was suggested that blood pressure could be influenced by injury alone and not specific to brain trauma. Studies examining the response in TBI, musculoskeletal and healthy controls would help to clarify this effect.

6.2. Concussion Assessment Measures

Data from the SCAT-2, POMS-SF and activity/sleep logs did provide information regarding assessment, recognition and clinical decisions related to mental activity. As advances in concussion research continue it has become evident that numerous systems and functions can be impaired post-injury. It is for this reason that studies examining a multitude of tasks and systems can be insightful.

Sport Concussion Assessment Tool-2

Along with the physical data that relates specifically to the component scores of the SCAT-2 and the total score we find that there are a number of factors that influence the usability of the SCAT-2.
Symptoms

Our findings are consistent with that of Lovell and colleagues in that baseline symptom scores are lower than post-concussion scores (2006). This is a general trend and is an assumption of the baseline assessment model. This model is questioned when post-concussion scores are lower than baseline, which occurred in three participants in this study. Furthermore we identify that although some participants indicate concussion like symptoms at healthy baseline; these same athletes report no symptoms following concussion. This is a common finding of athletes who are required to be symptom free prior to commencing the return to play protocol (Valovich Mcleod et al., 2012a). We see that communicating the requirements of return to play to athletes can have an impact on subjective symptom reporting which further hinders the ability to base decisions on symptom scores. Valovich McLeod and colleagues found a statistically significant difference in baseline scores when comparing athletes with and without a history of concussion (2012a). Similar to the findings in our study, those participants with a history of concussion experienced more concussion like symptoms at baseline testing. This finding could be related to long-term consequences of concussion or purposeful misrepresentation of symptoms in the event of injury. We know from the literature that athletes have skewed the results of concussion testing to expedite return to play (Bazarian et al., 2009; Mayfield et al., 2013; McCrea et al., 2003). The psychometric properties of self-report concussion symptom scales continue to be an area of interest in concussion research. One of the common complaints of such scales is their lack of psychometric power. A systematic review by Valovich McLeod and Leach (2012b) identified that of the sixty articles that met the inclusion criteria only 8 discussed the development of the scale from a psychometric perspective. The SCAT-2 symptom scale is one of the few that has demonstrated face and content validity. The major criticism of symptom scales is that because athletes are not always inclined to be truthful in their response the tool must account for this factor.

Glasgow Coma Scale (GCS)
Glasgow Coma Scale scores from this study found that all participants scored 15/15. This is a common finding in the literature for studies examining mild TBI and concussion (Valovich McLeod et al., 2012a). Although some would argue that this test could be removed from the SCAT-2 as it is generally scored at 15/15 in concussed populations, it is a usable test that may help to identify more serious forms of TBI when present.

Cognitive Evaluation (SAC Score)

Cognitive evaluation was obtained from the Standardized Assessment of Concussion (SAC) score. There are a number of factors that can influence SAC scores. Aside from the test itself, evidence suggests that the timing, version and previous experience with the test can influence scores (Ragan et al., 2009). Since the SAC is shown to lack difficulty and that many scores are found to be above an acceptable range for individual-centred testing standards, its utility is questioned (Ragan et al., 2009). Our findings are consistent with those of Ragan et al. who found high SAC scores (2009). Furthermore, we identified that mean post-injury SAC scores were higher than healthy baseline scores. We recognize that many factors can influence this finding, especially motivation to perform and practice effects. Ragan et al. found that different versions of the test have varying levels of difficulty; as such the version used at baseline may be easier or more difficult than post-injury which could account for such findings (2009).

Despite the comprehensive nature of the SCAT-2 and the repertoire of research it is based on it lacks psychometric properties that would enhance its utility. Although the symptom scale has been the subject of some research regarding its psychometric properties, the cognitive based evaluations lack data to support its use. From a clinical perspective few individuals indicate cognitive impairment following concussion and a learning effect has been shown with repeat testing (Ragan et al., 2009).

In light of the fact that we know some components to be too easy, a weighted system could be used to remove the impact of the items that are too easy so they do not skew the total SAC score. High school participants display different cognitive scores which may suggest that the SAC is an acceptable measure for this education level. Statistically significant differences on day of injury
and day 3 were found in high school athletes when compared to baseline scores (Mayfield et al., 2013). Our findings may differ from this study due to the timing of SCAT-2 completion and age and education level of participants.

One of the most concerning findings of our study, which is supported by Valovich McLeod and colleagues, are decreased SAC scores in participants with a previous history of concussion (2012a). This indicates that individuals with a history of concussion perform poorer on cognitive tests compared to participants with no previous history of concussion. This may indicate possible long-term cognitive consequences of concussion, but clearly more research is needed with larger sample size before this can be conclusively determined.

Balance Evaluation (BESS)

Balance was evaluated using the balance error scoring system (BESS). BESS data were similar to those obtained from the cognitive evaluation. Our findings show that average balance scores at baseline were lower than post-concussion scores for this sample, indicating poorer balance at baseline. This result is counterintuitive and is not supported by Mayfield and colleagues who found statistically lower balance scores post-concussion (2013). The difference in findings may be due to the fact that Mayfield et al. conducted the BESS on two surfaces which is a more difficult test (2013). Similar to SAC findings, there may be motivational factors and practice effects related to test performance.

Our balance findings found few errors both at baseline and post-concussion (baseline mean errors = 2.65, post-concussion mean errors = 2.1). This contrasts findings of a systematic review which identified an average of 10 and 17 errors during baseline and post-concussion respectively (Bell et al., 2011). Again this finding may be related to the age of participants and the BESS under two surface conditions.

Lastly we identify that those participants with a previous history of concussion perform poorer on baseline than those with no history of concussion. If these findings are evidence of long term consequences of concussion this would indicate the need for a systematic approach to retrain balance during concussion rehabilitation.
Profile of Mood States – short form (POMS-SF)

Increased mood disturbance is a common finding following injury, although relatively few studies have examined concussion specifically (Mainwaring et al., 2004). Mood disorders are a common outcome following TBI and pre-existing mood disorders and depression have been shown to be a predictor of poor outcome (Jorge & Robinson, 2003). Our findings displayed that the two participants who experienced a prolonged return to activity had the highest levels of TMD post-concussion. Whether these mood disturbances are related to the injury itself, the uncertainty of recovery or the removal from activity are unclear. Berlin and colleagues (2006) found that injury and subsequent cessation of regular exercise and fatigue, as reported on the POMS, lead to depressive symptoms. Although our findings did not indicate high depressive symptoms on the POMS-SF subscale, both participants with prolonged recovery reported high fatigue and low vigor. Evidence indicates that there is a time delay between removal from sport, increased fatigue and the development of depressive symptoms (Berlin et al., 2006). It is possible that depressive symptoms may have been identified if these participants had not withdrawn from the study and mood was assessed beyond the acute phase.

Mood states following injury are influenced by severity of injury, time of recovery, physical characteristics of injury and perception of injury (VanWilgen, Kaptein & Brink, 2010). Due to the uncertain nature of concussion, the varying timeline of recovery and lack of information regarding the injury, athletes who sustain concussion are at an increased risk to have negative mood states. Given that depressive mood states are related to prolonged recovery, the importance of addressing controllable factors is paramount.

Activity and Sleep Log

The activity and sleep logs included in year two of the study were created to record the self-reported quality and number of hours for each category of activity to examine the influence of activity and sleep on recovery from concussion. This tool was developed to provide additional qualitative and quantitative information regarding the daily activities of participants when physiological data were collected.
Activity Log

The finding of greatest interest gleaned from the activity log was that participants 4 and 6, who experienced prolonged return to activity, reported high mental activity in the acute phase following concussive injury. Research shows that physical activity in the acute phase can lead to detrimental long term consequences and prolonged return to play (Bazarian et al., 2009). It is for this reason that the Concussion In Sport Group advocates that no player return to activity the same day following injury (McCrorry et al., 2004). In recent years there has been an increased focus on the impact of mental activity following concussion and the impact on recovery. Research in younger populations advocate that school-aged athletes not return to sport prior to full return to school (Gagnon et al., 2009). Although this suggestion makes intuitive sense there is little data to support the impact of cognitive activity following concussion. Gibson and colleagues found that cognitive rest was not significantly associated with time of symptom resolution (2013). In some cases both too little and too much activity can have a detrimental effect on recovery (Sady, Vaughan & Gioia, 2011). Achieving the right balance of activities during the acute phase of injury is an on-going challenge.

Sleep Log

Our findings indicate that participants in our study self-rated the quality of their nighttime sleep at an average 7.6/10 post-concussion. This number may be slightly skewed towards a higher value as it includes all participants, even those who may not have had a concussion. Despite this inclusion we find that few sleep disturbances were reported via quality sleep rating. Research has shown the sleep disturbance in mTBI tends to be reported more during the sub-acute phase rather than during the initial days following injury (Orff, Ayalon & Drummond, 2009). If the timeline of data collection was conducted after 10 days post-concussion we may have identified a decreased self-reported sleep quality. Physically active individuals are shown to experience better circadian rhythm than non-athletes and it may be for this reason that sleep disturbances do not occur in the acute phase (Davenne, 2009).
Both quality and quantity of sleep are important factors to athletic performance. Sleep deprivation has been shown to lead to cognitive and memory impairment, decreased sustained attention and impaired response capability (Davenne, 2009), all of which have been identified as post-concussion findings (Boake et al., 2006). Given that it is unclear whether sleep impairment is a symptom of concussion or a factor which impairs recovery the need for further research is needed. Our participants reported achieving a mean 9.3 hours per night of sleep post-concussion. This exceeds that of high performance Olympic athletes who reported an average 7.8 hours per night (Samuels, 2012). This finding of an increased number of sleep hours may be indicative of increased fatigue and a need for increased sleep. A Pearson correlation was computed to assess the relationship between quality and quantity of sleep ($r = -0.22$, $n = 10$, $p = 0.2$). We found no relationship between sleep quality and quantity.

One of the challenges of addressing sleep disturbance in the TBI population is the impact of pharmacological interventions. Evidence suggests that there are neurocognitive effects related to the use of medication to regulate sleep patterns (Larson & Zollman, 2010). Sleep medication has been shown to impair neuroplasticity which is a critical process during recovery from brain injury (Orff, Ayalon & Drummond, 2009). Circadian rhythm is greatly influenced by the day-night environment. Because sensitivity to light is a common post-concussion complaint, many individuals may be unknowingly hindering their sleep-wake cycle by avoiding light (Davenne, 2009). Because of the link between sleep disturbance, depressive symptoms (Tsuno, Besset, Ritchie, 2005) and concussion, the importance of clarifying this relationship is essential to management, in an effort to prevent or limit secondary complications following injury.

6.3. Factors Affecting Interpretation of Results

Due to a lack of objectivity in current assessment techniques (i.e. relying on self-report) it is possible that participants were included in the study that did not have a concussion. There is no gold-standard test to accurately and objectively assess concussion in all cases. Two participants (3 & 5) displayed symptom scores below the level of baseline. Furthermore, many post-concussion physiological measures in these two participants showed relatively flat, unchanging trends. Both participants demonstrated high levels of activity and low levels of fatigue. In light
of these findings it can be hypothesized that these two participants experienced a rapid recovery or that they did not suffer a concussion. If it were the case that these two participants did not have a concussion it would skew the analysis.

As can be the case with traumatic injury, there exists the possibility that other injuries were sustained at the time of concussive injury. Although we did not track musculoskeletal injuries it is possible that the existence of a musculoskeletal injury could have had an impact on scores obtained on the measures collected to examine concussion effects. Furthermore, training schedules and timing of testing was not accounted for when assessing outcome measures. High performance athletes, like those who participated in this study, routinely undergo changes in training schedules in order to optimize performance. As a result, these training cycles could impact physiological and performance measures that were obtained in this study. In order to understand the true impact of concussion on these measures it would be important to distinguish results that could be related to changes in training. Along with the changes in training is the cessation of training and activity when injury occurs. Other studies examining concussion have used a musculoskeletal control group to account for changes related to not training (Mainwaring et al., 2004).

Evidence from the literature has identified that individuals with a history of concussion tend to experience longer recovery times, increased quality and quantity of symptoms and an increased potential for long term consequences (Asplund et al., 2004). Due to the potential for this group to respond in a different manner compared to participants with no history of concussion statistical analysis would have been enhanced by separate analysis.

6.4. Limitations

The two most significant limitations are related to methodology. Multiple baseline collection would have increased the ability to statistically analyze the data. Because of a singular data point during the baseline phase the options for statistical analysis were limited. In an ideal pre-post-test design, multiple baseline collection would allow us to determine a trend during the baseline phase and more accurately examine the response post-concussion.
The addition of matched controls would help to identify the natural variation that may occur in the physiological measures over time as well as possible practice effects. In the absence of a control group it is difficult to determine if there is the absence of a suspected trend that may be developmental or related to periodization of training in this population.

All post-concussion testing was conducted by the primary author, which represents a limitation due to lack of blinding on the part of the test administrator. Subsequently it is unknown what effect, if any, this may have had on participant test-taking performance.

Visual trend analysis was a method used to examine the post-concussion data. The approach was more consistent with a visual inspection versus a visual analysis. Visual inspection is less quantitative compared to trend analysis which generally employs a line of best fit, which can be used to compute the statistical probability (Hojem & Ottenbacher, 1988). The number of data collection points limited the availability of analysis to visual inspection which has been shown to produce decreased confidence with decision making when comparing methods (Hojem & Ottenbacher, 1988). There were four participants in this study who only had two data points which negated the possibility of identifying a pattern for these individuals. For the remaining participants with more than two data points a visual inspection was performed. Other methods of visual trend analysis use a specified value or number of points which represents a change. This is a truer version of visual trend analysis which provides a more methodological approach to the analyses. The number of data points was a limitation in the ability to visually analyze the data.

6.5. Future Directions

The findings of this thesis provide information that may guide future research or develop guidelines for clinical assessment and management of concussion.

6.5.1. Research Guidelines

Data from this pilot study have identified several areas that warrant further research. Larger scale projects including multiple baselines and matched controls would enhance the methodology of data collection. This would enhance the statistical analysis and validity of
findings from this project. Larger samples with a broader age range and gender distribution would enhance the generalizability of this research.

HRV findings identify impairment specifically in the acute phase following concussion. Collecting HRV data early in the post-concussion phase within hours of injury may further highlight its use as a diagnostic tool. We recognize that HRV collection and data present a few challenges but this small sample does provide a glimpse into the possibility of its use in concussion assessment. As with other concussion assessment tools there is a window in which tests are sensitive to the impact of concussion. Tests conducted after this time period often are not sensitive enough to identify concussion in the sub-acute phase, especially when the injury is on the mild end of the spectrum.

It was clear from the HRV data that many of the measures, even healthy baseline measures, were outside the expected normative data. Future studies could determine normative data for this population. Evidence from this research revealed that HRV values are highly individual which may be indicative of this population. HRV data collection may be enhanced by a more controlled environment. Collecting HRV with respiration protocols has been found to reduce the impact of irregular respiration on frequency domain measures (Kamath, Morilla & Upton, 2012).

HRV is a relatively novel technique to be assessed and its underlying mechanisms are not completely understood. It has been frequently used in the domain of cardiac disease, specifically as a predictor of morbidity and mortality (Kamath et al., 2012). Despite its usefulness in this regard there are still no guidelines or treatments to improve conditions that lead to decreased HRV (Keren et al., 2005; Katz-Leurer et al., 2010). As HRV is compounded by many physiological measures it cannot be used as a stand-alone method for any diagnosis or assessment. Lastly there are a variety of outcome measures regarding HRV. Determining which measures are most useful for the particular analysis would involve analysis of time, frequency and linear models of HRV.
We find that the majority of athletes who experienced concussion in this study were classified in sports that are considered non-contact. It is clear that concussion is not an injury specific to contact sport. Continued concussion research in all sports is warranted.

Despite research conducted on the structural validity and factor structure for the post-concussion symptom scale we find that additional work is warranted to enhance the use of this tool (Piland, Motl, Guskiewics, McCrea & Ferrara, 2006). The psychometric properties of this tool have not been rigorously studied. Further, the population utilizing this tool has self-interest in underreporting symptoms to expedite return to play. As such it should not be inherently evident to the participant how to falsify the test. A more psychometrically robust tool may require additional calculation on behalf of the clinician utilizing the tool but could provide more valid results.

6.5.2. Clinical Guidelines

One of the guiding principles behind this research was to consider the challenges that clinicians face when assessing and treating sport-related concussion. Although data collected represents a small, homogenous population there are some features that represent information that show potential for translation to clinical use.

Our findings from this study caution the use of the SCAT-2 as a stand-alone concussion assessment tool. We find that the data collected indicate a lack of sensitivity and specificity as an assessment tool. Furthermore we identify that practice effects may impact post-injury scores. Data from this research found that both cognitive and balance scores were greater post-injury which is counterintuitive. Although all participants were assessed with concussion based on results of the SCAT-2 and physician experience our data indicates that from a basic statistical standpoint the groups mean scores suggest that neither balance nor cognitive scores were useful as a diagnostic tool.

Our analysis of the SCAT-2 data highlighted some troubling results. The only differences that were identified from baseline to post-injury were that of the subjective symptom scores. It was
observed that both cognitive and balance scores were higher than pre-injury baseline. During the course of this study the third edition of the SCAT was developed, this newer version may address some of the concerns identified in this study.

Results from the prolonged recovery group indicate that high mental activity may be as detrimental to recovery as physical activity. In this regard providing strict guidelines for mental activity post-concussion is important for clinicians.

Physiological parameters highlighted support for further investigation of HRV as a possible indicator of concussion. Given that the technology and analysis of this data is feasible for the average clinician, implementing HRV as a baseline tool is reasonable.
7. Conclusions

We have identified that post-concussion measurement of heart rate variability, blood pressure and grip strength are safe and feasible. No adverse events were reported.

Baseline testing has been a mainstay of concussion assessment and is used heavily in assessing readiness to return to activity. Although no relationship was found between physiological measures and post-concussion symptoms, cognition and balance we find these concussion assessment tools to be of little value on their own. Based on this case study and small sample size we find the use of the SCAT-2 to be limited in its ability to assess concussion. Mood states and activity logs identified that increased negative subscales of the POMS-SF and mental activity in the acute phase were common factors amongst two participants who experienced prolonged return to play. The activity log developed for this study provided clinically meaningful data to highlight the possible influence of mental activity in the acute phase. Secondly, this tool may assist with activity decisions in an effort to create an optimal balance for individuals during recovery.

Physiological measures of grip strength and blood pressure revealed that the majority of measures fall within normal limits and that they are not significantly different compared to baseline scores. The measurement of HRV revealed possible use as an identification tool and that prolonged low HRV may be an indicator of prolonged recovery. This study provides original evidence to a growing body of literature that may influence both research and clinical practice.
References


http://circ.ahajournals.org/content/93/5/1043.full


Appendices

Appendix 1 Return to Play Guidelines (SCAT2)

_Return to play_
Athletes should not be returned to play the same day of injury. When returning athletes to play, they should follow a stepwise symptom-limited program, with stages of progression. For example:
1. rest until asymptomatic (physical and mental rest)
2. light aerobic exercise (e.g. stationary cycle)
3. sport-specific exercise
4. non-contact training drills (start light resistance training)
5. full contact training after medical clearance
6. return to competition (game play)

There should be approximately 24 hours (or longer) for each stage and the athlete should return to stage 1 if symptoms recur. Resistance training should only be added in the later stages.

**Medical clearance should be given before return to play.**
Appendix 2 Demographic Questionnaire

Demographic Profile

Name: ___________________________________

Age: ______

Gender: Male Female

Main Sport: ______________________________

# Of Previously diagnosed concussions: ____________
Appendix 3 Informed Consent Document

Informed Consent – Post concussion testing without baseline

Title: Baseline Measures for Concussion: Assessment of Physiological Data

You are being asked to participate in a research study. Before you give your consent to be a volunteer, it is important that you read the following information and ask as many questions as necessary to be sure you understand what you will be asked to do.

My name is Danielle Dobney (BA, Hons) and I am a part-time Masters student in the Graduate Department of Rehabilitation Science at the University of Toronto. I’m a Certified Athletic Therapist at Ryerson University, studying sports-related concussion. I am supervised by Dr. Michelle Keightley (Ph.D. Psychology) Clinical Neuropsychologist and faculty member in the Department of Occupational Science and Occupational Therapy at the University of Toronto. This purpose of this research study is to obtain measures that are relevant to the study of concussion. This information can be used in the future to see the effect of concussion on heart rate and blood pressure readings.

I am seeking healthy, varsity athletes (ages 18-30) with no history of cardiovascular disease and currently not taking medication which may affect heart rate and blood pressure readings. You are invited to participate in this research study.

Concussion will be identified by Athletic Therapy staff, including myself and Jerome Camacho (Head Athletic Therapist). All participants who are suspected of a concussion will be referred to Dr. Darren Edelist (MD, CCFP, dip Sport Med CAESM) for diagnosis.

For the 2012-2013 season Ryerson Athletic Therapy will be expanding its concussion protocol to include this research study. Having your data included in the research is voluntary and you may refuse to have your data included in the study, at any time, without penalty or loss of benefits to which you are otherwise entitled. Your choice of whether or not to exclude your individual data will not influence your present or future relations with Ryerson University or the University of Toronto. Several questionnaires are being administered, and you have the choice of not answering any questions, if you don’t feel comfortable in answering.
You may be excluded from participation (at any time) if you have or develop cardiovascular disease, medical conditions related to heart rate, rhythm or blood pressure or a history of psychiatric or mental health conditions or are taking medication for such.

**What You Will Be Asked To Do?**
As a participant in this study you will be tested if you get a concussion this season. You will be asked to fill out 4 brief questionnaires (5 minutes), perform a grip strength test (1 minute) and have your blood pressure and heart rate measured (10 minutes). You will be re-tested for the first 3 days and then alternate days until you recover. Your final re-test will be 2 weeks following recovery. The time to complete the testing takes approximately 20 minutes and will take place in the Ryerson Athletic Therapy Clinic (Mattamy Athletic Centre – Room# TBD). Return to play decisions will not be influenced by your participation in this study. The current standard of practice regarding return to activity will be unchanged by this research study.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Time</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sport Concussion Assessment Tool 2</td>
<td>5 min</td>
<td>Assesses symptoms, cognitive skills and balance/coordination.</td>
</tr>
<tr>
<td>2. Demographic Questionnaire</td>
<td>1 min</td>
<td>Information about yourself, age, gender and sport history.</td>
</tr>
<tr>
<td>3. Blood Pressure</td>
<td>5 min</td>
<td>Automated machine to take your blood pressure.</td>
</tr>
<tr>
<td>4. Heart Rate</td>
<td>5 min</td>
<td>Automated machine assesses your heart rate.</td>
</tr>
<tr>
<td>5. Grip Strength</td>
<td>1 min</td>
<td>Test to determine your ability to generate power by squeezing with your hand.</td>
</tr>
<tr>
<td>6. Mood Questionnaire</td>
<td>5 min</td>
<td>Asks you to rank 30 feelings on a scale of 0-5.</td>
</tr>
<tr>
<td>7. Activity and sleep log</td>
<td>1 min</td>
<td>Rates the quality and quantity of your activities and sleep</td>
</tr>
</tbody>
</table>

**TOTAL TIME** ~25 min

**Access to Research Information:**
Information retrieved from the research study will be kept completely confidential. Access to information will be restricted to the research team. All study files identifying information will be kept in locked cabinets in Danielle Dobney’s office located at (Mattamy Athletic Centre – Room# TBD). Data will be retained for 7 years and then destroyed.

**Risks / Benefits:**
You may experience slight discomfort during blood pressure measurements. This would involve temporary increased pressure around the upper arm. Measurement for heart rate may cause slight discomfort from a chest strap used in the transmission of heart rate information.
In the event that any adverse findings are identified in the baseline testing you will be referred to Dr. Darren Edelist (sport medicine physician).

Confidentiality / Publication of Results
No individual identifiers will be used, each participant will be assigned a subject code and this information will be stored in a password protected document. Compliance with the Personal Health and Information Protection Act (PHIPA) will be followed. Any information obtained from this research will be kept confidential.

This research may be used to make public presentations or submitted to scholarly publication. Your personal identity will not be revealed and your information will remain confidential.

Contact Information:
If you have any questions about this study, please contact:
Danielle Dobney, 416-979-5000 ext. 6125
danielle.dobney@ryerson.ca

If you have questions regarding your rights as a human subject and participant in this study, you may contact:

Ryerson University Research Ethics Board
Research Ethics Board
c/o Office of the Vice President, Research and Innovation
Ryerson University
350 Victoria Street
Toronto, ON M5B 2K3
416-979-5042
CONSENT FORM

Baseline Measures of Concussion: Physiological Data

The researcher explained this study to me. I have read the letter and understand what this study is about.

Your signature below indicates that you have read the information in this agreement and have had a chance to ask any questions you have about the study. Your signature also indicates that you agree to be in the study and have been told that you can change your mind and withdraw your consent to participate at any time. You have been given a copy of this agreement.

You have been told that by signing this consent agreement you are not giving up any of your legal rights.

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

PART 1

You agree to participate in the following aspects of this study:

In the event that you get a concussion, you agree to participate in the following tests according to the schedule outlined above;

1. Complete a questionnaire about my mood and symptoms (3 minutes)
2. Complete a concussion test (5 minutes)
3. Do a grip strength test (1 minute)
4. Have my Blood Pressure and Heart Rate Measured (10 minutes)

Concussion recovery generally takes 7-10 days. There is no clear timeline of recovery. In some cases recovery can take weeks or months.
Consent Without Baseline Test:

Signing your name means that you agree to take part in these aspects of the study.

You agree to participate in the above mentioned aspects of this study. You know you can change your mind at any time.

_________________________  _________________________  ____________
Name (please print)        Signature                     Date

I confirm that I have explained the study to the participant to the extent compatible with the participant’s understanding, and that the participant has agreed to be in the study.

_________________________  _________________________  ____________
Researcher’s Name          Signature                     Date
Appendix 4 Sport Concussion Assessment Tool 2 (SCAT2)
Cognitive & Physical Evaluation

1 Symptom score (from page 1)
   22 minus number of symptoms
   of 21

2 Physical signs score
   Was there loss of consciousness or unresponsiveness? Y N
   Was there a loss of balance or dizziness? Y N
   Physical signs score (1 point for each negative response)
   of 2

3 Glasgow coma scale (GCS)
   Eye opening response     1
   Eye opening to pain       2
   Eye opening to speech     3
   Speech response           4
   Best verbal response (V)  1
   Incomprehensible sounds  2
   Confused                  3
   Oriented                 4
   Best motor response (M)   5
   Motor response            1
   Abnormal reflex to pain   2
   Positive reflex to pain   3
   Localizing to pain        4
   Obey commands            5
   Glasgow Coma score (E + V + M) of 15
   GCS should be recorded for all athletes in case of subsequent concussions.

4 Sideline Assessment – Muddocks Score
   Modified Muddocks questions (1 point for each correct answer)
   All what sense are we at today? 0 1
   Which half is it now? 0 1
   Who scored last in this match? 0 1
   What team did you play last week? 0 1
   Did your team win the last game? 0 1
   Muddocks score of 5
   Muddocks score is validated by sideline diagnosis of concussion only and limited included in SCAT2 summary score for serial testing.

Cognitive Assessment

Standardized Assessment of Concussion (SAC)

Orientation (1 point for each correct answer)
   What month is it? 0 1
   What is the date today? 0 1
   What is the day this week? 0 1
   What year is it? 0 1
   What time is it right now? (written in 24 hour)
   Orientation score of 5

Immediate memory
   "I am going to read you a list of words and when I am done, repeat back as many words as you can remember, in any order."
   Trials 2 & 3:
   "I am going to repeat the same list again. Repeat back as many words as you can remember, in any order, even if you said the word before.
   Complete at 3 trials regardless of score in trial 1 & 2. Read the words at a rate of one per second. Scale: 1 point for each correct response. Total score equals sum across all trials. Do not inform the athlete that delayed recall will be tested.

   List
   Trial 1 Trial 2 Trial 3 Alternative word list
   elbow 0 1 0 1 0 1 canny baby finger
   apple 0 1 0 1 0 1 paper monkey penny
   carpet 0 1 0 1 0 1 sugar perfume blanket
   saddle 0 1 0 1 0 1 umbrella tursen lemon
   bubble 0 1 0 1 0 1 wagon horn insect
   Total Immediate memory score of 15

Concentration
   Digits Bivocated:
   "I am going to read you a string of numbers and when I am done, you will repeat them back to me backwards in reverse order of how I read them to you. For example, #1 7 9 8, you would say 8 7 9 1.
   If correct, go to next string length. If incorrect, repeat trail 2 and 1 point for each string length. Stop after incorrect on both trials. The delay should be read at the rate of one per second.

   Alternating digt lists
   4 0 3 0 1 0 1 0 1 0 1 0 1 0 1
   3 0 1 0 1 0 1 0 1 0 1 0 1 0 1
   2 0 1 0 1 0 1 0 1 0 1 0 1 0 1
   4 1 5 0 1 0 1 0 1 0 1 0 1 0 1
   3 4 6 0 1 0 1 0 1 0 1 0 1 0 1
   2 1 3 4 5 0 1 0 1 0 1 0 1 0 1
   Months in Reverse Order:
   "Now tell me the months in the year in reverse order. Start with the last month and go backward. So you’ll say December. November... Go ahead!"
   1 point for entire sequence correct.
   Dec Nov Oct Sept Aug Jul Jun May Apr Mar Feb Jan 0 1
   Concentration score of 5

SCAT2 SPORT CONCUSSION ASSESSMENT TOOL | PAGE 3
6 Balance examination

The balance testing is based on a modified version of the Balance Error Scoring System (BESS). A slip or fall with a second hand is required for a test to be passed.

**Balance testing**

1. Stand on your toes with your eyes open. If you are not able to stand on your toes, you may stand on your heels. If you are able to stand on your toes, you should stand on your heels.
2. Keep your hands on your hips or in front of you.
3. You will be counted if you lose balance for 30 seconds.
4. You will lose balance if you lose balance for 30 seconds.
5. You will lose balance if you lose balance for 30 seconds.

**Conditions**

- Double leg stance: both feet on your non-dominant foot.
- Single leg stance: one foot on your non-dominant foot.
- Tandem stance: both feet on your non-dominant foot.
- Standing on your non-dominant foot.
- Balance examination score (30 minute tests):

<table>
<thead>
<tr>
<th>Condition</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double leg stance</td>
<td>10</td>
</tr>
<tr>
<td>Single leg stance</td>
<td>10</td>
</tr>
<tr>
<td>Tandem stance</td>
<td>10</td>
</tr>
<tr>
<td>Balance examination score</td>
<td>30</td>
</tr>
</tbody>
</table>

7 Coordination examination

**Upper limb coordination**

Finger to nose: Use your finger to touch your nose as quickly and accurately as possible.

- Which arm scored: Left, Right
- Score out of 3: 1

**Cognitive assessment**

**Standardized Assessment of Concussion (SAC)**

**Delayed recall**

**Overall score**

<table>
<thead>
<tr>
<th>Test measure</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptom scale</td>
<td>5/7</td>
</tr>
<tr>
<td>Physical signs scale</td>
<td>5/5</td>
</tr>
<tr>
<td>Glasgow Coma Scale (GCS)</td>
<td>15</td>
</tr>
<tr>
<td>Coordination scale</td>
<td>1/2</td>
</tr>
<tr>
<td>Orientation scale</td>
<td>4/5</td>
</tr>
<tr>
<td>Immediate memory scale</td>
<td>3/3</td>
</tr>
<tr>
<td>Concentration scale</td>
<td>4/5</td>
</tr>
<tr>
<td>Delayed recall scale</td>
<td>1/5</td>
</tr>
<tr>
<td>SAC total</td>
<td>2/2</td>
</tr>
<tr>
<td>SACS total</td>
<td>1/10</td>
</tr>
<tr>
<td>Muddocks Scale</td>
<td>4/5</td>
</tr>
</tbody>
</table>

Definitive normative data for a SACS “cut-off” score is not available at this time and will be developed in prospective studies. It is recommended that the SACS score be used separately in concussion management. The scoring system takes into account specific clinical significance during serial assessments where it can be used to diagnose either a decline or an improvement in functional performance.

Scoring data from the SACS should not be used as a stand-alone method to diagnose concussion, measure recovery or make decisions about an athlete’s readiness to return to competition after concussion.
Athlete Information

Any athlete suspected of having a concussion should be removed from play, and then seek medical evaluation.

Signs to watch for
Problems could arise over the first 24-48 hours. You should not be left alone and must go to a hospital at once if you:
- Have a headache that gets worse
- Are very dizzy or can’t be awakened (secked up)
- Can’t keep people in place
- Have repeated vomiting
- Refuse unusually or seem confused; are very irritable
- Have seizures (arms and legs jerk uncontrollably)
- Have weak or numb arms or legs
- Are unsteady on your feet; have slurred speech

Remember, it's better to be safe. Consult your doctor about suspected concussion.

Return to play
Athletes should not be returned to play the same day of injury. When returning athletes to play, they should follow a stepwise symptom-limited program, with stages of progression. For example:
1. Rest until asymptomatic (physical and mental rest) 2. Light aerobic exercise (e.g., stationary cycle) 3. Sport-specific exercise 4. Non-contact training drills (start light resistance training) 5. Full contact training after medical clearance 6. Return to competition (game play)

There should be approximately 24 hours (or longer) for each stage and the athlete should return to stage 1 if symptoms occur. Resistance training should only be added in the later stages. Medical clearance should be given before return to play.

<table>
<thead>
<tr>
<th>Task</th>
<th>Test domain</th>
<th>Time</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCAFT</td>
<td>Symptom score</td>
<td>Date tested</td>
<td>Up post injury</td>
</tr>
<tr>
<td></td>
<td>Physical signs score</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glasgow Coma Score (E / V / M)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Imbalance examination score</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Orientation score</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Immediate memory score</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Concentration score</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delayed recall score</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAC</td>
<td>SAC score</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Symptom severity score (max possible 132)

Additional comments

Concussion injury advice (To be given to concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. It is expected that recovery will be rapid, but the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, dizziness, worsening headache, double vision or excessive drowsiness, please telephone the clinic or the nearest hospital emergency department immediately.

Other important points:
- Rest and avoid strenuous activity for at least 24 hours
- No alcohol
- No sleeping tablets
- Use paracetamol or codeine for headache. Do not use opioids or anti-inflammatory medication
- Do not drive until medically cleared
- Do not train or play sport until medically cleared

Clinic phone number

SCT2 SPORT CONCUSSION ASSESSMENT TOOL | PAGE 4

Contact details or stamp
Appendix 5 Profile of Mood States - Short Form (POMS-SF)

POMS SF PROFILE OF MOOD STATES-SHORT FORM
Below is a list of words that describe feelings people have. Please read each one carefully. Then circle ONE answer to the right, which best describes HOW YOU HAVE BEEN FEELING DURING THE PAST 24 HOURS.

The numbers refer to these phrases:
0—not at all
1=a little
2=moderately
3=quite a bit
4=extremely

1. Tense..............0 1 2 3 4
2. Angry..............0 1 2 3 4
3. Worn out........0 1 2 3 4
4. Unhappy..........0 1 2 3 4
5. Lively.............0 1 2 3 4
6. Confused.........0 1 2 3 4
7. Peeved...........0 1 2 3 4
8. Sad...............0 1 2 3 4
9. Active............0 1 2 3 4
10. On Edge.........0 1 2 3 4
11. Grouchy......0 1 2 3 4
12. Blue.............0 1 2 3 4
13. Energetic.......0 1 2 3 4
14. Hopeless........0 1 2 3 4
15. Uneasy........0 1 2 3 4
16. Restless.........0 1 2 3 4
17. Unable to
    Concentrate....0 1 2 3 4
    things.............0 1 2 3 4
18. Fatigued........0 1 2 3 4
19. Annoyed........0 1 2 3 4
20. Discouraged.....0 1 2 3 4
21. Resentful........0 1 2 3 4
22. Nervous.........0 1 2 3 4
23. Miserable.......0 1 2 3 4
24. Cheerful........0 1 2 3 4
25. Bitter...........0 1 2 3 4
26. Exhausted.......0 1 2 3 4
27. Anxious.........0 1 2 3 4
28. Helpless........0 1 2 3 4
29. Weary...........0 1 2 3 4
30. Bewildered.....0 1 2 3 4
31. Furious.........0 1 2 3 4
32. Full of pep.....0 1 2 3 4
33. Worthless.......0 1 2 3 4
34. Forgetful.......0 1 2 3 4
35. Vigorous........0 1 2 3 4
36. Uncertain about
# Appendix 6 Activity and Sleep Log

Name: ___________________________  Date of Injury: ___________________________

<table>
<thead>
<tr>
<th>Date</th>
<th>Physical Activity</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Practice</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strength Training</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Physical Activity Intensity</td>
<td>/10 /10 /10 /10 /10 /10 /10 /10</td>
</tr>
<tr>
<td></td>
<td>Other</td>
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<table>
<thead>
<tr>
<th>Mental Activity</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading</td>
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</tr>
<tr>
<td>Computer</td>
<td></td>
</tr>
<tr>
<td>Studying</td>
<td></td>
</tr>
<tr>
<td>Writing</td>
<td></td>
</tr>
<tr>
<td>Mental Activity Intensity</td>
<td>/10 /10 /10 /10 /10 /10 /10 /10</td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social Activity</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time with friends</td>
<td></td>
</tr>
<tr>
<td>Television</td>
<td></td>
</tr>
<tr>
<td>Video Games</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time you went to bed</td>
</tr>
<tr>
<td>---------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Time you woke up</td>
<td></td>
</tr>
<tr>
<td># of Hours napping</td>
<td></td>
</tr>
<tr>
<td>Quality of nighttime</td>
<td>/10</td>
</tr>
<tr>
<td>sleep</td>
<td></td>
</tr>
<tr>
<td># of times waking at</td>
<td></td>
</tr>
<tr>
<td>night</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 7 HF vs. Time with Trend line and r-squared

HF (HRV) vs. Time

- 4FH2
- 6FH1
- 7FB2
- 8FB2
- Linear (4FH2)
- Linear (6FH1)
- Linear (7FB2)
- Linear (8FB2)
Appendix 8 LF:HF vs. Time with Trend line and r-squared

Appendix 9 Total Power vs. Time with Trend line and r-squared
Appendix 10 MAP vs. Time with Trend line and r-squared

![MAP vs. Time graph]

Appendix 11 Dominant Grip vs. Time with Trend line and r-squared

![Mean Dominant Grip vs. Time graph]
Appendix 12 Non-Dominant Grip vs. Time with Trend line and r-squared

Mean Non-Dominant Grip vs. Time

Time (Days)

<table>
<thead>
<tr>
<th>Days</th>
<th>KG</th>
<th>R²</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>20.0</td>
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</tr>
<tr>
<td>2</td>
<td>25.0</td>
<td>0.0019</td>
</tr>
<tr>
<td>4</td>
<td>30.0</td>
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<tr>
<td>6</td>
<td>35.0</td>
<td>0.7814</td>
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<tr>
<td>8</td>
<td>40.0</td>
<td>0.2162</td>
</tr>
<tr>
<td>10</td>
<td>45.0</td>
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</tbody>
</table>

Legend:
- 1M56
- 4FH2
- 6FH1
- 7FB2
- 8FB2
- Linear (1M56)
- Linear (4FH2)
- Linear (6FH1)
- Linear (7FB2)
- Linear (8FB2)
Appendix 13 HRV Normative Data

Heart Rate Variability

Table 5.
Normal Values of Standard Measures of HRV

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Normal Values (mean±SD)</th>
</tr>
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<tbody>
<tr>
<td><strong>Time Domain Analysis of Nominal 24 hours [8]</strong></td>
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</tr>
<tr>
<td>SDNN</td>
<td>ms</td>
<td>141±39</td>
</tr>
<tr>
<td>SDANN</td>
<td>ms</td>
<td>127±35</td>
</tr>
<tr>
<td>RMSSD</td>
<td>ms</td>
<td>27±12</td>
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<tr>
<td>HRV triangular index</td>
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<td>37±15</td>
</tr>
<tr>
<td><strong>Spectral Analysis of Stationary Supine 5–min Recording</strong></td>
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</tr>
<tr>
<td>Total power</td>
<td>ms$^2$</td>
<td>3466 ±1018</td>
</tr>
<tr>
<td>LF</td>
<td>ms$^2$</td>
<td>1170±416</td>
</tr>
<tr>
<td>HF</td>
<td>ms$^2$</td>
<td>975±203</td>
</tr>
<tr>
<td>LF</td>
<td>nu</td>
<td>54±4</td>
</tr>
<tr>
<td>HF</td>
<td>nu</td>
<td>29±3</td>
</tr>
<tr>
<td>LF/HF ratio</td>
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<td>1.5–2.0</td>
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</tbody>
</table>
Appendix 14 HRV Scatterplots

**Total Power HRV and Symptoms**

**Total Power HRV and Total Mood Disturbance**
Total Power HRV and Sleep Quality

- Total
- Linear (Total)