THE EFFECT OF OSTEOPATHIC MANUAL TREATMENT ON CONCUSSION INJURY REHABILITATION

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ABSTRACT

Duplex-Doppler ultrasonography was used to identify changes in blood flow velocity and volume as a result of concussion; and the Sport Concussion Assessment Tool, 5th Edition (SCAT5) was used to determine the effect of osteopathic manual treatment (OMT) on participant recovery. Ten healthy participants (mean age 24.70 yrs, n= 5 female) and thirteen symptomatic concussed participants (mean age 26.54 yrs, n= 7 female) were recruited and screened using a health questionnaire and the SCAT5. Significant differences between healthy versus concussed individuals for the SCAT5 total number of symptoms, $t(15.51) = 3.11$, $p = .008$, and SCAT5 symptom severity, $t(13.15) = 3.33$, $p = .005$ were found. There was a trend toward decreased cerebral blood flow velocity (CBFV) between healthy versus concussed individuals, $t(21) = 1.41$, p = 0.17. These results provide support that OMT may improve cerebral hemodynamics and decrease symptom burden and severity in a concussed population.

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I would like to thank Dave Murray who introduced me to osteopathy. Dave took brilliant care of me while I was playing soccer at McMaster University, but it was not until my third concussion that I knew osteopathy was my calling. This thesis is dedicated to all those individuals who have sustained a concussion and so desperately needed support but could not find the answers. I believe osteopathy will profoundly help.

To Loriann Hynes, the moment I met you I knew we would make a great team. You are truly a special person. Your work ethic and compassion are admirable, and I cannot thank you enough for being my advisor.

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TERMINOLOGY

Abbreviation	Expanded Word
CBF	Cerebral blood flow
CBFV	Cerebral blood flow velocity
OMT	Osteopathic manual treatment
mTBI	Mild traumatic brain injury
WHO	World Health Organization
CISG	Concussion in Sport Group
SRC	Sports related concussion
SCAT	Sport concussion assessment tool
Glut	Glutamate
K^+	Potassium
Na^+	Sodium
Ca^{2+}	Calcium
ATP	Adenosine triphosphate
PCS or PCD	Post-concussion syndrome or post-concussion disorder
CCO	Canadian College of Osteopathy
ICA	Internal carotid artery
VA	Vertebral artery
IJV	Internal jugular vein
PC-MRI	Phase contrast magnetic resonance imaging
TAMEAN	Time-averaged mean velocity
ASL	Arterial spin labelling
C0	Occipital condyle
C1	Atlas or cervical vertebrae 1
C2	Axis or cervical vertebrae 2
C3	Cervical vertebrae 3
SBS	Sphenobasilar symphysis
OM	Occipital mastoid
SSTET	Sub-symptom threshold exercise training
RCT	Randomized control trial
CESD-R	The Center for Epidemiologic Studies Depression Scale – Revised
NPDI	Neck Pain Disability Index

Chapter One: Literature Review

Introduction

Altered cerebral blood flow (CBF), is seen in both animal (Giza & Hovda, 2014; Pasco et al., 2007) and human (Churchill, Hutchison, et al., 2017a; Doshi et al., 2015; Lin et al., 2016; Meier et al., 2015; Peng et al., 2016; Wang et al., 2016) models of concussion. Manual therapy, specifically osteopathic manual treatment (OMT), has been used in concussion management for years (Magoun, 2011; Still, 1908; Sutherland, 1939); however, despite the lengthy history, there is limited evidence-based research providing support that osteopathy is an effective treatment option for concussion symptoms. The purpose of the current research is twofold. First, to determine whether duplex-Doppler ultrasonography, an inexpensive and accessible tool, can be used to identify potentially abnormal changes in cerebral blood flow as a result of concussion; and second, to determine the effect of OMT on cerebral hemodynamics and participant recovery from concussion based on self-reported symptoms.

The term concussion was first mentioned in the writings of Hippocrates (460–370 BC) in the Hippocratic corpus (McCrory & Berkovic, 2001). Although Hippocrates was the first to mention the term, it was not clearly described until the 10^{th} century by a physician, Rhazes (AD 865-925 AD) (McCrory & Berkovic, 2001; Modanlou, 2008). Rhazes defined concussion as an abnormal physiological state rather than a severe brain injury (McCrory & Berkovic, 2001).

Considering the term concussion dates back to ancient history, one would expect a clear consensus of the definition today; this is not the case. There continues to be a lack of consensus of the definition to date. Both the terms concussion and mild traumatic brain injury (mTBI) are used separately and interchangeably in the literature, which can be confusing for individuals suffering from, and clinicians providing care for, these conditions.

According to the World Health Organization (WHO) Collaborating Centre for Neurotrauma, Prevention, Management and Rehabilitation Task Force mild traumatic brain injury can be defined as an acute brain injury caused by a biomechanical force that results in a disturbance in brain function (Carroll, Cassidy, Holm, Kraus, & Coronado, 2004). To be considered a mTBI there must be: (i) one or more of the following: confusion or disorientation, loss of consciousness for 30 minutes or less, post-traumatic amnesia for less than 24 hours, and/or other neurological changes as determined by a neuropsychological assessment; and (ii) Glasgow Coma Scale score of 13-15, 30 minutes post injury (Holm, Cassidy, Carroll, & Borg, 2005). A concussion, according to the Concussion in Sport Group (CISG), can be defined as a traumatic injury caused by a biomechanical force due to either a direct or indirect blow to the head, face, neck or body resulting in a transient disturbance in neurological function (McCrory et al., 2017).

Both definitions are continually evolving but as of late, a defining difference between the terms is related to symptomology. A concussion is transient in nature and a mTBI is permanent or semi-permanent (Willer & Leddy, 2006). All concussions are mTBIs, but not all mTBIs are concussions (Banks & Domínguez, 2019). A mTBI can be classified as complicated, with injuries that have intracranial findings; or uncomplicated, such as a concussion (Choe & Giza, 2015; Conder & Conder, 2014). For purposes of this paper the term concussion will be used.

Annual concussion prevalence in Canada is 110 per 100,000 people; the true annual rate most likely exceeds this number as underreporting remains high (Dobson, Yarbrough, Perez, Evans, & Buckley, 2017; Gordon, Dooley, & Wood, 2006). Currently, there is no gold standard diagnostic test or marker that health care practitioners can use to diagnose a concussion (McCrory et al., 2017). Without a gold standard test available, practitioners rely on a multifaceted approach to diagnose a concussion. The battery of neurocognitive and neuropsychological tests, postural assessments, and subjective symptom reporting currently used has a high sensitivity rate (exceeding 90%) for concussion diagnosis (Broglio, Macciocchi, & Ferrara, 2007). The Sport Concussion Assessment Tool 5th Edition (SCAT5) is currently the most well-established concussion assessment tool and includes a combination of neurocognitive and neuropsychological tests, postural assessments, and subjective symptom reporting (McCrory et al., 2017).

One of the major changes to the SCAT5 from previous versions of SCAT3 and SCAT2 include updated guidelines for the Symptom Evaluation (a graded symptom checklist) in a baseline setting (Echemendia et al., 2017). These changes were implemented by the CISG, a committee and expert panel of Sports Related Concussion (SRC) researchers and clinicians. Prior to the changes, after sustaining a concussion, individuals self-reported their concussion symptoms based on how they felt in the moment; “their state of being”, now they report how they typically feel; “their general traits”. These changes to the SCAT5 Symptom Evaluation were implemented to more closely align with standardized questionnaires used in a clinical setting such as the Beck Depression Inventory (BDI) (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961), the Center for Epidemiologic Studies Depression Scale (CES-D) (Radloff, 1977) and the State-Trait Anxiety Inventory (STAI) (Spielberger & Gorsuch, 1983).

CONCUSSION PATHOPHYSIOLOGY

The neurometabolic cascade of a concussion is a complex process that involves functional or microstructural injury to neural tissue (Giza & Hovda, 2014). The process has been clearly documented in animal studies and corroborated in human studies (Giza & Hovda, 2014). The cascade begins with axonal damage and inflammation that leads to cellular damage and membrane disruption (Figure 1) (Barrett, McBurney, & Ciappio, 2014). As a result of concussion nerve cells undergo changes in membrane potential beginning with an ionic flux and a release of glutamate (Glut) (Giza & Hovda, 2001, 2014). According to Giza and Hovda (2014), headache, photophobia, and phonophobia may be clinically correlated to the rapid ionic flux. Following the release of the excitatory neurotransmitter Glut, there is an efflux of potassium ions (K^+) into the extracelluar fluid and an influx of sodium ions (Na^+) into the intracellular fluid, which causes cellular depolarization (Banks & Domínguez, 2019; Giza & Hovda, 2001, 2014). Cellular depolarization disrupts cell homeostasis (Banks & Domínguez, 2019).

As injury severity increases so does the amount of K+ released from the cell (Banks & Domínguez, 2019). The dramatic change in Glut release and K+ efflux causes over-activation of Glut receptors and voltage gated calcium (Ca^{2+}) channels, which in turn causes intracellular levels of Ca^{2+} to rise (Banks & Domínguez, 2019; Giza & Hovda, 2001; Zetterberg, Smith, & Blennow, 2013). Elevated levels of intracellular Ca^{2+} may lead to an accumulation of Ca^{2+} in the mitochondria of nerve cells that could cause impaired oxidative metabolism (hyperglycolysis) (Banks & Domínguez, 2019; Giza &

Hovda, 2001). To restore homeostasis adenosine triphosphate (ATP) is required but due to increased energy demands the nerve cell often depletes its glucose store (Banks & Domínguez, 2019; Giza & Hovda, 2001). Insufficient glucose supplies leads to lactate accumulation and a cerebral energy crisis (Giza & Hovda, 2001). The cerebral energy crisis usually occurs in an area where there is decreased blood flow, which causes metabolic uncoupling (a mismatch between energy supply and demand) (Giza & Hovda, 2014). The energy crisis may also be one reason for slowed cognitive function post concussion (Giza & Hovda, 2014).

Metabolic uncoupling paired with hyperglycolysis can cause impaired metabolism for seven- to ten-days, which may vary with age, with younger animals showing shorter periods of impairment (~3 days) (Giza & Hovda, 2014). Some researchers report a full recovery from concussion within 10- to 14-days in humans with only 10% of individuals experiencing symptoms past this period (McCrory et al., 2017; Willer & Leddy, 2006). Others report a full recovery from concussion within 90 days post injury with up to 33% of individuals experiencing symptoms past this period (Binder, Rohling, & Larrabee, 1997; Karr, Areshenkoff, & Garcia-Barrera, 2014; Leddy, Kozlowski, Fung, Pendergast, & Willer, 2007; Rimel, Giordani, Barth, Boll, & Jane, 1981; Rohling, Larrabee, & Millis, 2012). The true timeframe for recovery is unknown and individualistic; however, the individuals who continue to experience symptoms are typically the ones who are desperate for treatment and support.

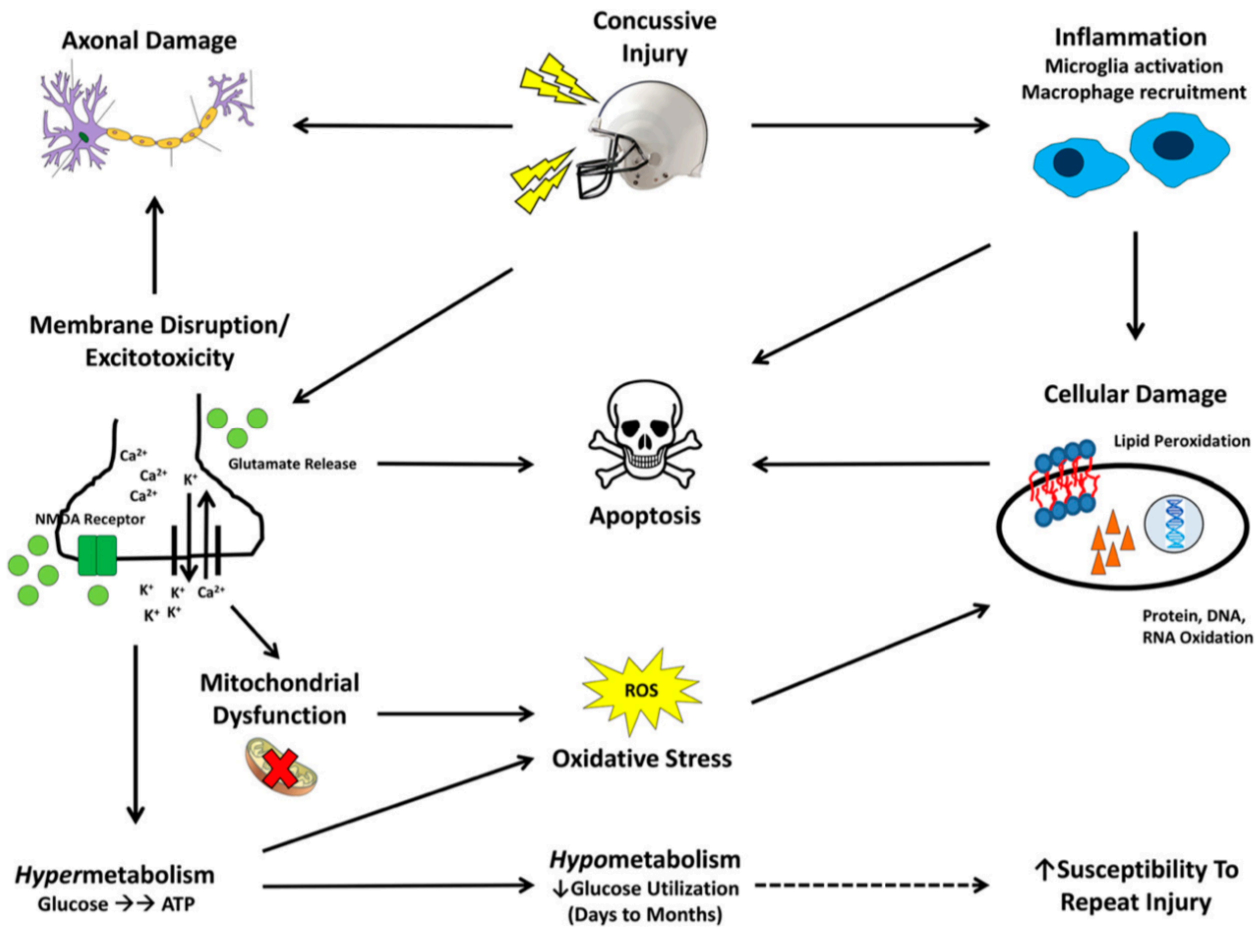


Figure: 1. Simplified neurometabolic cascade diagram (Barrett et al., 2014, p. 269)

Post-Concussion Symptoms and Manual Therapy

The neuropathology of a concussion is complex and expression varies between individuals suffering. Individuals with prolonged symptoms are often placed in a Post-Concussion Syndrome (PCS) category. The WHO's International Classification of Disease (ICD) 10th revision (2016), defines PCS as a syndrome that follows head trauma, which includes several symptoms such as: headache, dizziness, fatigue, irritability, insomnia, concentration or memory difficulty, and/or reduced tolerance to stress. On the other hand, PCS was recently removed from the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) and is now captured under neurocognitive disorders associated with brain injury as persistent concussive symptoms (Polinder et al., 2018).

Ellis, Leddy, and Willer (2015) proposed a framework for classifying post-concussion disorders (PCD) in patients with persistent symptoms greater than three weeks post injury. Three categories were identified: physiologic PCD, which is characterized by global impairments in brain metabolism; vestibulo-ocular PCD, which is characterized by symptoms affecting the vestibulo-ocular system and cervicogenic PCD, which is characterized by dysfunction of the cervical spine and somotosensory system (Ellis et al., 2015). This framework has been used to inform manual therapy research in relationship to concussion treatment options.

Schneider et al. (2014) conducted a randomized control trial treatment intervention study for concussed individuals aged 12 to 30 years. The primary outcome was time to medical clearance and individuals were seen weekly for 8 weeks or until the time of medical clearance (Schneider et al., 2014). Participants in the experimental group received individually designed treatment plans consisting of cervical spine physiotherapy and vestibular rehabilitation (Schneider et al., 2014). Cervical spine physiotherapy consisted of manual therapy to the cervical and thoracic region and cervical neuromotor and sensorimotor retraining exercises (Schneider et al., 2014). Results showed that individuals who received cervical spine physiotherapy and vestibular rehabilitation were medically cleared to return to sport at a faster rate than controls (Schneider et al., 2014).

Grabowski, Wilson, Walker, Enz, and Wang (2017) conducted a retrospective study on physical therapy treatment approaches for patients with post-concussion syndrome. A multimodal approach to treatment was performed and included cervicothoracic manual therapy and exercise, vestibular oculomotor rehabilitation and cardiovascular exercise (Grabowski et al., 2017). The retrospective design, lack of control group and varied treatment plans for participants were limitations of the design. However, findings led to the development of a framework for referral guidelines for manual therapy treatment at three to four weeks post injury based on their findings and findings from previous research (Griesbach, Hovda, Molteni, Wu, & Gomez-Pinilla, 2004; Majerske et al., 2008). Research into the effectiveness of this framework has yet to be published.

Osteopathic Manual Treatment and Concussion

The study of osteopathy is rooted in anatomy and physiology, which are necessary components to reason treatment. “Osteopathy cannot be imparted by books” (Still, 1908, p. 192). Symptomology is a guide and there is no one direct path for treatment. Osteopathic manual treatment (OMT) can be defined by the five-model concept, which was accepted by the WHO in 2006 and includes: the biomechanical (postural muscles, spine and extremities), respiratory-circulatory (thoracic inlet, thoracic and pelvic diaphragms, tentorium cerebelli and costal cage), neurological (head, brain, spinal cord, autonomic nervous system, peripheral nerves), behavioural (brain), and metabolic-energy (internal organs and endocrine glands) models (Chila (Ed.), 2011). The first three models (biomechanical, respiratory-circulatory and neurological) along with anatomy and physiology and input from senior osteopathic practitioners from the Canadian College of Osteopathy (CCO), were used to guide the techniques selected for this study. However, to truly understand the treatment methodology selected by an osteopathic practitioner, you must first understand the pathophysiology.

Provided with the anecdotal accounts from previous osteopaths (Magoun, 2011; Still, 1908; Sutherland, 1939) and with the limited published research (Castillo, Wolf, & Rakowsky, 2016; Chappell, Dodge, & Dogeby, 2015; Guernsey, Leder, & Yao, 2016; Moskalenko et al., 2009; Moskalenko et al., 2016; Patel & Sabini, 2018) there is support that treatment of the craniosacral mechanism and the vitality of the person may be beneficial in concussion recovery. The craniosacral mechanism is a functional unit that connects the brain, spinal cord and sacrum, and includes cerebrospinal fluid (CSF), the falx cerebri, tentorium cerebelli, falx cerebelli, and spinal dural membranes (Magoun, 2011). William Garner Sutherland was a pioneer in cranial osteopathy (Magoun, 2011). He described concussion treatment in reference to the central nervous system (CNS), craniosacral mechanism, and the cranium with specific mention of the vault (Sutherland, 1939). According to Magoun (2011), the rehabilitation of whiplash type injuries, such as concussion, must consider the pelvis, spine, cranium and all segmentally related structures.

The effects of spinal manipulation can cause specific and regional responses with changes observed in areas away from the site of manipulation (Bialosky, Bishop, Price, Robinson, & George, 2009; Borges, Bortolazzo, & Neto, 2018; Cleland, Childs, McRae, Palmer, & Stowell, 2005). These changes can be both structural and physiological (Pelletier, Higgins, & Bourbonnais, 2015). Negative neuroplastic changes can result from chronic pain; however, the contrary also exists. Positive neuroplastic changes can result from targeted therapy (Pelletier et al., 2015). Specifically, spinal manipulation may result in plastic changes in sensorimotor and meso-limbic prefrontal areas (Haavik & Murphy, 2012; Pelletier et al., 2015). A systematic review by Borges et al. (2018) found osteopathy exerts an influence on autonomic modulation depending on the site of manipulation. A greater parasympathetic (PNS) response can be found with cervical and lumbar manipulations, and a greater sympathetic (SNS) response with thoracic manipulations.

A retrospective study by Chappell et al. (2015), on the effects of OMT on SRC symptoms revealed all 26 individuals improved on all symptoms reported on the SCAT2 Symptom Evaluation. Osteopathic treatments were individualized and included a variety of direct (such as spinal manipulations and decompactions) and indirect (such as exaggeration of lesion) techniques. Results were statistically significant for 10 of the 22 symptoms as well as the overall symptoms assessed (Chappell et al., 2015). The 10 statistically significant symptoms included: headache, pressure in head, balance problems, sensitivity to noise, feeling like in a fog, don’t feel right, difficulty concentrating, fatigue or low energy, irritability and sadness (Chappell et al., 2015).

Two published case studies provide anecdotal support that OMT may be helpful for concussion management. Guernsey et al. (2016) found that a 27-year old man, following a snowboarding accident, had immediate resolution of dizziness, tinnitus, and nausea symptoms post OMT, with complete resolution of symptoms one-week post treatment. Castillo et al. (2016) found a 16-year old girl, with history of three head injuries, had decreased headache, vertigo, dizziness, memory and concentration problems, phonophobia, and photophobia after a single OMT session directed at cranial and cervical dysfunction. After six OMT sessions her Concussion Symptom Score

(CSS) was 0/144 and her Balance Error Scoring System (BESS) was 14/30, down from her original scores of 53 and 22, respectively (Castillo et al., 2016). A pilot study on the safety of osteopathic cranial manipulative medicine by Patel and Sabini (2018) provided evidence that cranial osteopathy is a safe treatment option for concussion-related symptoms and recovery. A total of seven subjects were included; none reported adverse effects of treatment and five demonstrated improvements in their Post-Concussion Symptom Scale (PCSS) score (Patel & Sabini, 2018). Together these studies provide correlational evidence that OMT is a safe and effective treatment option for concussed individuals.

Cerebral Hemodynamics and Concussion

Cerebral blood flow (CBF) is the sum of volume measurements of the left and right vertebral arteries (VA) and internal carotid arteries (ICA). CBF can adapt to changes in vascular resistance and can recalibrate in response to variations in blood or perfusion pressure making it remarkably stable (Strandgaard & Paulson, 1984). Flow volume of each vessel is a measurement of the product of the time-averaged (mean) velocity (TAV or TMEAN) and cross-sectional area of the vessel (Blanco, 2015). Phase contrast magnetic resonance imaging (PC-MRI) is primarily used to determine CBF, however duplex Doppler ultrasound is a comparable and reliable measure of CBF (Khan et al., 2017). This finding could potentially influence how concussions are diagnosed and treated as duplex Doppler ultrasound is readily accessible when compared to PC-MRI.

After concussion, there is evidence of cerebral edema (Kors et al., 2001) that may be due to the ionic flux (Giza & Hovda, 2014). Through arterial spin labelling (ASL) and MRI neuroimaging studies researchers have found increased (Churchill, Hutchison, et al., 2017a; Doshi et al., 2015) and decreased CBF (Churchill, Hutchison, et al., 2017a; Lin et al., 2016; Meier et al., 2015; Peng et al., 2016; Wang et al., 2016) following concussion in both the acute and subacute phases (ranging from 24 hours to one month). These phases have yet to be fully defined but previous research has defined the acute phase as the first 24-48 hours, when rest is prescribed; and the subacute phase may be defined as the following 7- to 14-days, when spontaneous resolution of symptoms is thought to occur (Giza & Hovda, 2014; McCrory et al., 2017).

A neuroimaging study using T1 weighted MRI and ASL, provided preliminary results that the SCAT5 symptom severity scale may be associated with CBF, with higher symptoms correlated to increased CBF (Churchill, Hutchison, Graham, & Schweizer, 2017). However, a high cognitive symptom score was correlated with decreased CBF in frontal and subcortical (caudate and insula) regions, when compared to somatic symptom scores (Churchill, Hutchison, Graham, et al., 2017). CBF appears to be more sensitive to changes in specific regions of interest (ROI) (Churchill, Hutchison, et al., 2017a; Doshi et al., 2015; Ge et al., 2009; Grossman et al., 2013; Meier et al., 2015; Peng et al., 2016). As such, ASL and MRI may serve as better physiological measures to evaluate changes in CBF to evaluate specific areas of the brain as a result of concussion. Duplex-Doppler ultrasound is well-suited to evaluate cerebral blood flow velocity (CBFV) and overall CBF post-concussion.

Cerebral blood flow volume and velocity can be measured from vessels in the neck via internal carotid (ICA) and vertebral (VA) arteries and is calculated as the sum of the flow volumes and velocities of the left and right ICA and VA (Schöning, Walter, & Scheel, 1994). This relationship was first demonstrated by Schöning et al. (1994), who validated Doppler ultrasound as a comparable and reliable alternative measure of CBF to the nitrous oxide method and the Xenon inhalation and single-photon emission computed tomography technique (Schöning & Scheel, 1996).

As previously mentioned, there are several non-invasive imaging techniques available to measure CBF but only phase contrast magnetic resonance imaging (PC-MRI) and duplex-Doppler ultrasonography allow for individual assessment of specific vessels (Ho, Chan, Yeung, & Metreweli, 2002). Slight errors in blood volume quantification due to incorrect diameter measurements, torturous vessels, turbulent or nonaxial blood flow, larger vessel movement or velocities discrepancies may be reported with Doppler ultrasonography (Ho et al., 2002). In PC-MRI CBFV measures have been reported to be significantly lower (~30%) when compared to Doppler ultrasound (Khan et al., 2017; Oktar et al., 2006), however; Doppler ultrasound can yield important velocity information in a clinical setting as errors in recording are often due to torturous vessels (Oktar et al., 2006). Despite these potential errors, measures of CBF are comparable and correlated in PC-MRI and Doppler ultrasound (Khan et al., 2017) and other researchers have reported the value of Doppler ultrasound in a clinical setting (Albayrak et al., 2007; Oktar et al., 2006; Scheel, Ruge, & Schöning, 2000; Schöning & Scheel, 1996; Schöning et al., 1994).

Chapter Two: Manuscript

Introduction

Annual concussion prevalence in Canada is 110 per 100,000 people; the true annual rate most likely exceeds this number as underreporting remains high (Dobson et al., 2017; Gordon et al., 2006). A concussion according to the Concussion in Sport Group (CISG) is a traumatic injury caused by a biomechanical force due to either a direct or indirect blow to the head, face, neck or body resulting in a transient disturbance in neurological function (McCrory et al., 2017). It is important to note there is an absence of imagining abnormalities in concussion injuries and a step-wise resolution of symptoms. A mild traumatic brain injury (mTBI) according to the World Health Organization (WHO) Collaborating Centre for Neurotrauma, Prevention, Management and Rehabilitation Task Force can be defined as an acute brain injury caused by a biomechanical force that causes a disturbance in brain function (Carroll et al., 2004). To meet the WHO's criteria for an injury to be considered a mTBI there must include: (i) one or more of the following: confusion or disorientation, loss of consciousness for 30 minutes or less, post-traumatic amnesia for less than 24 hours, and/or other neurological changes as determined by a neuropsychological assessment; and (ii) Glasgow Coma Scale score of 13-15, 30 minutes post injury (Holm et al., 2005). The definitions are used separately and interchangeably in the literature; however, the key difference is that a concussion and its associated symptoms are considered *transient* in nature. All concussions are mTBIs but not all mTBIs are concussions (Banks & Domínguez, 2019). A mTBI can be classified as complicated, with injuries that have intracranial findings; or uncomplicated; such as a concussion (Choe & Giza, 2015; Conder & Conder, 2014).

Research has indicated that 90% individuals suffering from a concussion recover within 10- to 14-days without treatment and only 10% of individuals experience symptoms past this period (McCrory et al., 2017; Willer & Leddy, 2006). Within this subset of individuals, the majority will make a full recovery by 90 days (3 months) post injury but up to 33% will continue to experience post-concussive symptoms beyond this period (Binder et al., 1997; Karr et al., 2014; Leddy et al., 2007; Rimel et al., 1981; Rohling et al., 2012). These are the individuals who require individualized care and a multifaceted approach to rehabilitation because their symptoms do not resolve spontaneously without intervention.

There is a paucity of concussion manual therapy rehabilitation research. In a randomized control trial conducted by Schneider et al. (2014) results showed individuals aged 12 to 30 years old who received cervical spine physiotherapy and vestibular rehabilitation were medically cleared to return to sport at a faster rate than controls. The experimental group received individually designed treatment plans consisting of cervical spine physiotherapy (manual therapy to the cervical and thoracic region) and vestibular rehabilitation (cervical neuromotor and sensorimotor retraining exercises) (Schneider et al., 2014). Both groups were seen weekly for up to 8 weeks and performed range of motion exercises, stretches and postural education.

A recent retrospective study by Grabowski et al. (2017) on physical therapy treatment approaches for patients with post-concussion syndrome provided support for a multimodal approach to concussion treatment (Grabowski et al., 2017). The retrospective design, lack of control group and varied treatment plans for participants were limitations of the design but nonetheless important for future research.

Osteopathic manual treatment (OMT), a form of manual therapy, has been used in concussion management for years (Magoun, 2011; Still, 1908; Sutherland, 1939); however, despite the lengthy history, there is limited evidence-based research providing support that osteopathy is an effective treatment option for concussion symptoms. OMT can be defined by the five-model concept, which was accepted by the WHO in 2006 and includes: the biomechanical (postural muscles, spine and extremities), respiratory-circulatory (thoracic inlet, thoracic and pelvic diaphragms, tentorium cerebelli and costal cage), neurological (head, brain, spinal cord, autonomic nervous system, peripheral nerves), behavioural (brain), and metabolic-energy (internal organs and endocrine glands) models (Chila (Ed.), 2011).

A retrospective osteopathic study by Chappell et al. (2015), found all participants improved on the Sport Concussion Assessment Tool 2nd Edition (SCAT2) Symptom Evaluation post OMT. Results were statistically significant for 10 of the 22 symptoms as well as the overall symptoms assessed. The 10 statistically significant symptoms included: headache, pressure in head, balance problems, sensitivity to noise, feeling like in a fog, don’t feel right, difficulty concentrating, fatigue or low energy, irritability and sadness (Chappell et al., 2015). This study along with two published case studies (Castillo et al., 2016; Guernsey et al., 2016) provide anecdotal support that OMT may be helpful for concussion management.

Without a gold standard test available, practitioners rely on a multifaceted approach to diagnose a concussion. A battery of neurocognitive and neuropsychological tests, postural assessments, and subjective symptom reporting is highly sensitive (exceeding 90%) to concussion diagnosis (Broglio et al., 2007). The Sport Concussion

Assessment Tool 5th Edition (SCAT5) is currently the most well-established concussion assessment tool and includes a combination of neurocognitive and neuropsychological tests, postural assessments, and subjective symptom reporting (McCrory et al., 2017).

One of the major changes to the SCAT5 from previous versions included updating the guidelines for the Symptom Evaluation (a graded symptom checklist) (Echemendia et al., 2017). Previously, individuals self-reported their concussion symptoms based on how they felt in the moment; “their state of being”, now they report how they typically feel; “their general traits”. These changes to the SCAT5 Symptom Evaluation were implemented to more closely align with standardized questionnaires used in a clinical setting such as the Beck Depression Inventory (BDI) (Beck et al., 1961), the Center for Epidemiologic Studies Depression Scale (CES-D) (Radloff, 1977) and the State-Trait Anxiety Inventory (STAI) (Spielberger & Gorsuch, 1983).

The pathophysiology of a concussion is variable, and no two concussions are the same. Both animal (Giza & Hovda, 2014; Pasco et al., 2007) and human (Churchill, Hutchison, et al., 2017a; Doshi et al., 2015; Lin et al., 2016; Meier et al., 2015; Peng et al., 2016; Wang et al., 2016) models of concussion have shown altered cerebral blood flow (CBF) post-concussion. Current research in humans has shown increased CBF post-concussion (Churchill, Hutchison, et al., 2017a; Doshi et al., 2015) while others have found the opposite; decreased CBF (Churchill, Hutchison, et al., 2017a; Lin et al., 2016; Meier et al., 2015; Peng et al., 2016; Wang et al., 2016). It is important to note the majority of the studies evaluated CBF in the acute stage with varying reference ranges of *acute* (ranging from 24 hours to 10 days). The researchers who evaluated CBF in the *subacute* stage (ranging from 3 days to one month) all found CBF to be reduced (Lin et al., 2016; Meier et al., 2015; Peng et al., 2016). These phases have yet to be fully defined and inconsistencies remain within the literature. The CISG (2017) defined the acute phase as the first 24-48 hours, when rest is prescribed; and the subacute phase may consist of the following 7- to 14-days, when spontaneous resolution of symptoms is thought to occur but no consistent definition of this phase exists in the literature (Giza & Hovda, 2014; McCrory et al., 2017).

Cerebral blood flow volume and velocity can be measured from vessels in the neck via internal carotid (ICA) and vertebral (VA) arteries and is calculated as the sum of the flow volumes and velocities of the left and right ICA and VA (Schöning et al., 1994). This relationship was first demonstrated by Schöning et al. (1994), who validated Doppler ultrasound as a comparable and reliable alternative measure of CBF to the nitrous oxide method and the Xenon inhalation and single-photon emission computed tomography technique (Schöning & Scheel, 1996). There are several non-invasive imaging techniques available to measure CBF but only phase contrast magnetic resonance imaging (PC-MRI) and duplex-Doppler ultrasonography allow for individual assessment of specific vessels (Ho et al., 2002). In PC-MRI CBFV measures have been reported to be significantly lower (~30%) when compared to Doppler ultrasound (Khan et al., 2017; Oktar et al., 2006), however; Doppler ultrasound can yield important velocity information in a clinical setting as errors in recording are often due to torturous vessels (Oktar et al., 2006). Despite these potential errors, measures of CBF are comparable and correlated in PC-MRI and Doppler ultrasound (Khan et al., 2017) and other researchers have reported the value of Doppler ultrasound to measure CBF in a clinical setting (Albayrak et al., 2007; Oktar et al., 2006; Scheel, Ruge, & Schöning, 2000; Schöning & Scheel, 1996; Schöning et al., 1994).

Within the current study duplex-Doppler ultrasonography was used to measure objective changes in cerebral blood flow (CBF) as a result of concussion as well as the effects of osteopathic manual treatment (OMT). The SCAT5 was used to determine the perceived effect of OMT on participant recovery from concussion. It is hypothesized that regional OMT specific to the pelvis, spine and head will restore cerebral hemodynamics in concussed individuals and in turn will improve blood flow and subjective symptom reporting.

METHODS

Individuals between the ages of 18 and 40 years were recruited, inclusive of all races and activity levels. This reference range was selected because CBF volume remains relatively constant from 18 to 60 years of age (Scheel, Ruge, Petruch, & Schöning, 2000; Schöning et al., 1994). Recruited individuals were separated into two groups, healthy and concussion. Individuals were included in the concussion group if they were symptomatic or they were between 10- and 90-days post-injury. The reference range of 10- to 90-days post-injury was selected because at 10- to 14-days post-injury approximately 90% of individuals suffering from concussion symptoms will have spontaneous resolution of symptoms (McCrory et al., 2017; Willer & Leddy, 2006) and an additional 7% will have complete resolution of symptoms at 90 days post-injury (Binder et al., 1997; Karr et al., 2014; Leddy et al., 2007; Rimel et al., 1981; Rohling et al., 2012). Therefore, the selected inclusion criteria for the concussed group aimed to capture the 10% of concussed individuals with lingering post-concussion symptoms who did not recover spontaneously without intervention. All concussions were physician diagnosed. Individuals were included in the healthy group if they reported no history of concussion. All individuals with cerebrovascular or cardiovascular disease, chronic headache, diabetes, cancer and clinical depression were excluded. All participants refrained from consuming caffeine two hours prior to each session.

Intervention

Informed consent was obtained prior to study commencement. Ethics was obtained from the York University Office of Research Ethics and the Human Participants Review Committee (HPRC).

All participants attended three sessions: two treatment sessions and a follow-up data collection session, approximately two weeks apart (Figure 2). The treatment was provided by a single therapist (the primary researcher) who was blinded to the results until study competition.

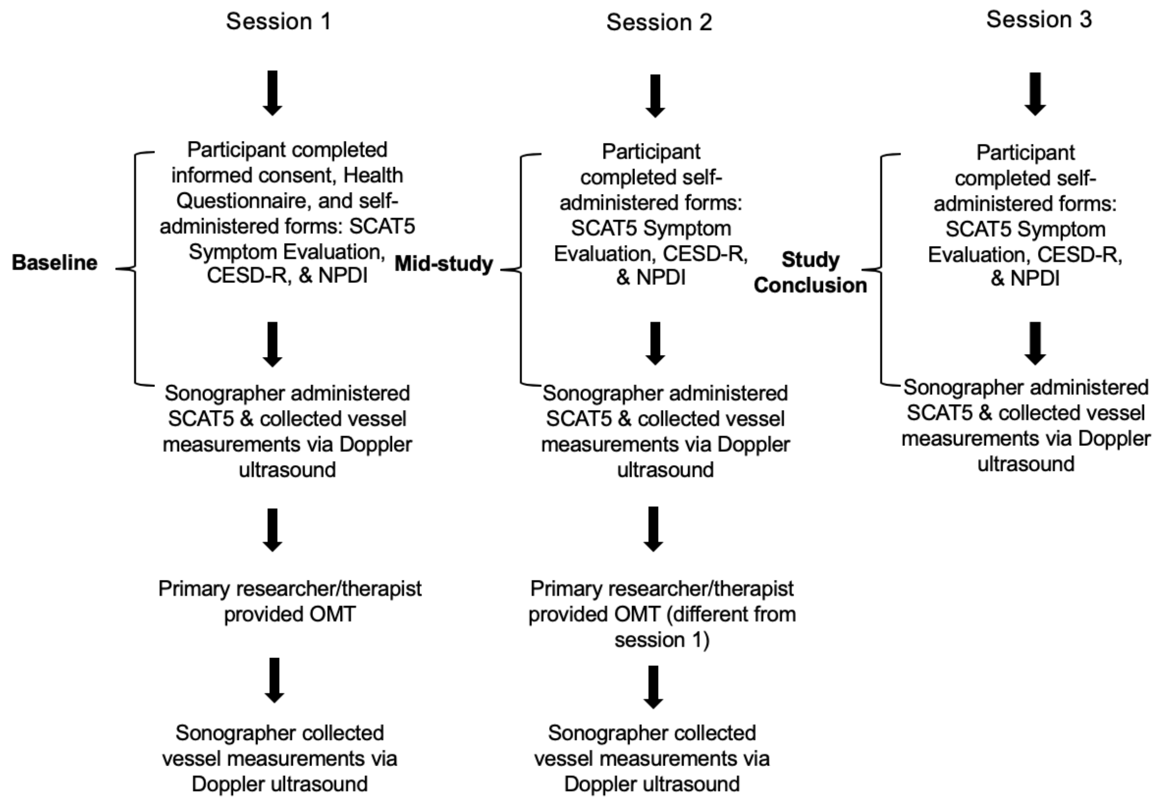


Figure: 2. Research procedure flow diagram for this study

OMT was provided at the first and second session. Treatment 1 was provided at the first session and treatment 2 at the second session (Table I). All participants regardless of their grouping received the same treatment protocol.

TABLE: I. OSTEOPATHIC ASSESSMENTS & TECHNIQUES PROVIDED DURING THE STUDY

OSTEOPATHIC MANUAL TREATMENT 1	**OSTEOPATHIC MANUAL TREATMENT 2**
• C0 – C1, C1 – C2, C1/C2 – C3 compaction treatment • SBS assessment & decompaction • OM suture assessment & decompaction • Tentorium cerebelli & falx cerebri assessment & treatment • Assessment & treatment of non-physiological without respect to axis lesions of the sacrum, spine and ribs • Anterior cervical fascia treatment • Core link	• Assessment & treatment of the 3 diaphragms • Cranial bone compaction assessment & treatment • Laura Leslie, DO temporal decompaction technique • Venous sinus technique • Posterior fossa technique • Cerebrum/cerebellum balancing • Normalization of the lateral ventricles

During the first session, upon completion of informed consent, participants completed a Health Questionnaire (Appendix A). In all sessions, participants completed three self-administered assessments: SCAT5 Symptom Evaluation (Appendix B), The Center for Epidemiologic Studies Depression Scale - Revised (CESD-R) (Appendix C) and The Neck Pain Disability Index (NPDI) (Appendix D). Following completion of the self-administered assessments, the SCAT5 assessment (Appendix E) was administered by the secondary researcher and sonographer, who then recorded ultrasound measurements of six neck vessels: left and right ICA, VA and internal jugular vein (IJV). All measurements were recorded using the Logiq e Ultrasound System (GE Healthcare) with a 4-12 MHz linear array transducer in a supine position after an initial period of rest (~10 min). OMT was provided following the blood flow measurement data collection in the first and second session. Post-intervention ultrasound measurements of the same vessels were recorded in the first two sessions.

In the second session, the same process was completed as during the first session; however, a different osteopathic manual treatment was provided (Table I). In the third and final session, the three self-administered assessments, the SCAT5 and six neck vessel measurements were collected, and no manual therapy was provided. For a schematic of the study procedure refer to Figure 2.

Doppler Ultrasound Data Collection

Blood flow volume, velocity and diameters of the left and right ICA, VA and IJV were measured using the 4-12 MHz linear array transducer for the Logiq e Ultrasound System (GE Healthcare). The ICA was imaged at the level of the bifurcation or slightly above at approximately the level of the C4 (Figure 3(a)) and the VA was imaged at the level of the intertransverse segments of the vertebrae (Figure 3(b)). The IJV was located in the transverse plane (Figure 3(c)) and imaged in a longitudinal plane (Figure 3(d)). To ensure measurements were as uniform as possible an angle-corrected measurement was taken across the entire vessel lumen with an insonation angle of 60^o. B-mode videos were recorded for 20 seconds from which measurements were taken for mean blood flow velocity, diameter and volume over three consecutive cardiac cycles.

Measurements were recorded during diastole when the velocity profile becomes parabolic and the mean velocity is approximately half the maximum velocity (Albayrak et al., 2007). Measurements were recorded in this phase to avoid overestimation of blood flow velocities and volumes (Albayrak et al., 2007). Total CBF was calculated as a sum of the volume measurements of the left and right VA and ICA (Schöning et al., 1994). Volume (mL/min) was calculated as: time-averaged mean velocity (TAMEAN) (cm/s) x cross-sectional area of the vessel (cm^2) x 60s (Blanco, 2015). Vessel diameters were calculated using $A=\pi(d/2)^2$, where A is the cross-sectional area; and d is the vessel diameter (Blanco, 2015). Total CBFV was calculated as a sum of the TAMEAN measurements of the left and right VA and ICA.

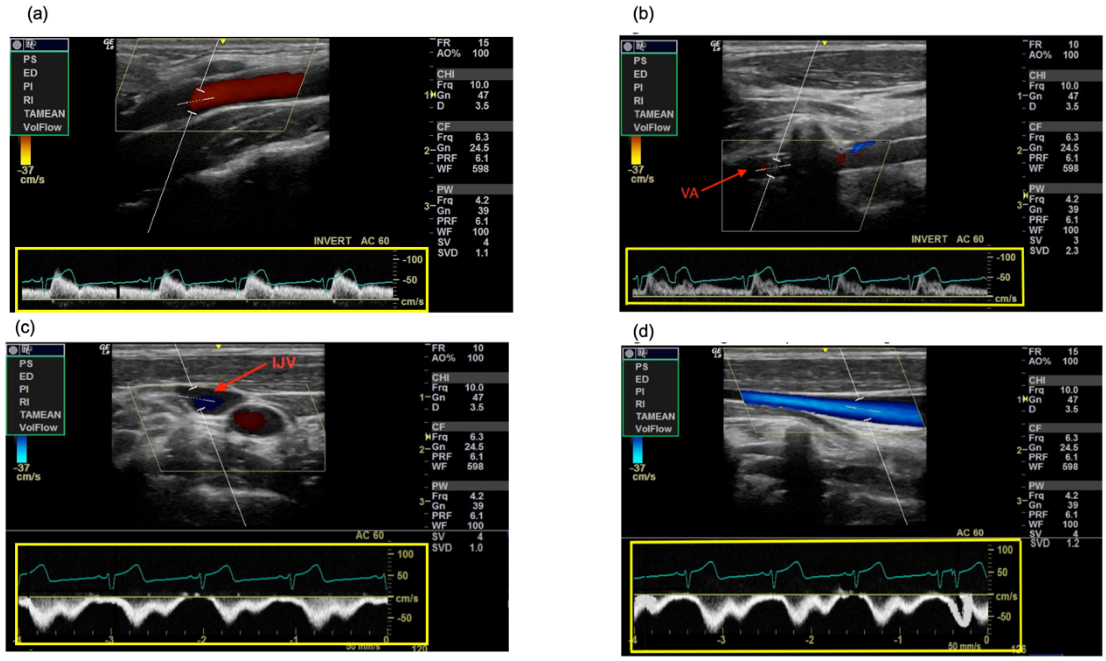


Figure: 3. ICA at the level of bifurcation (a). VA at the level of the intertransverse segments of the vertebrae (b). IJV in the transverse plane (c). IJV in the longitudinal plane (d).

Statistical Analysis

Two-tailed, independent t-tests were used to identify significant differences between healthy versus concussed individuals using the baseline and the study conclusion measures, across the following variables: CBF, CBFV, IJV volume, IJV velocity, SCAT5 total number of symptoms, and SCAT5 symptom severity. Assumptions of normality were first verified using Shapiro-Wilk tests and confirmed for all variables except SCAT5 total number of symptoms and SCAT5 symptom severity, which were non-normal. Mann-Whitney U tests, which are non-parametric and do not require assumptions of normality to be met, were used to verify the statistical results for these two variables. Levene's test was used to test for homogeneity of variance and adjusted values were used if required. Statistical values were corrected for multiple comparisons using the Bonferroni method; as a result, a significance criterion of $p < .008$ was used (.05/6 planned comparisons). All statistical analyses were conducted using SPSS v. 25 (IBM Corp. Armonk, New York).

RESULTS

A total of twenty-five individuals (mean age 25.74 yrs, n=12 female) were recruited and screened for inclusion. One participant was excluded due to a concussion sustained during the protocol and another excluded due to a Doppler ultrasound recording error. Demographics and descriptive statistics are outlined in Table II. There were no significant differences between sex or age (categories included 18-23, 24-29 and 30+). There were no significant differences between healthy versus concussed individuals for the variables CBF, CBFV, IJV volume, IJV velocity over the three sessions (Table III). There was, however, a trend toward decreased CBFV between healthy versus concussed individuals, $t(21) = 1.41$, $p = 0.17$ between baseline and study conclusion measurements, demonstrating a change in CBFV after manual therapy intervention (Figure 4). Ten of the thirteen (75%) concussed participants had decreased CBFV whereas only four healthy (40%) participants had decreased CBFV. This trend is important in a clinical setting as CBFV shows promise as a measure to monitor changes in physiology in concussed individuals.

There was a significant difference between healthy versus concussed individuals for the SCAT5 total number of symptoms reported, $t(15.51) = 3.11$, $p = .007$, as well as SCAT5 symptom severity, $t(13.15) = 3.33$, $p = .005$ over the three sessions. Overall, concussed participants reported both fewer and less severe symptoms over time than healthy participants (Figure 5(a) and (b)). Since SCAT5 total number of symptoms and

SCAT5 symptom severity both did not meet assumptions of normality, Mann-Whitney U tests were used to verify the results obtained using the t-tests. Both tests remained significant using this alternate method: SCAT5 total number of symptoms, U = 21.5, p = .01, SCAT5 symptom severity, U = 14.00, p < .01.

TABLE: II. DEMOGRAPHICS AND DESCRIPTIVE STATISTICS EVALUATING THE IMPACT OF OSTEOPATHIC MANUAL TREATMENT BETWEEN BASELINE AND STUDY CONCLUSION SCORES

Metric	***Healthy***	***Concussion***
Sample Size, n	10	13
Age, y	24.70 ± [20, 36]	26.54 ± [18, 36]
Female, n	5	7
CBF	-19.55 ± 46.58	-44.19 ± 45.56
CBFV	0.41± 3.98	-7.71 ± 4.02
IJV (volume)	42.82 ± 51.03	60.96 ± 36.41
IJV (velocity)	2.55 ± 1.91	1.20 ± 2.17
Symptoms No., (SCAT5)	-2.10 ± 0.60	-7.23 ± 1.54
Symptom Severity (SCAT5)	-3.10 ± 1.03	-19.00 ± 4.66

Abbreviations: SCAT5, Sport Concussion Assessment Tool-5th Edition
Age is reported mean ± [min, max], all other distributions are reported mean difference (baseline – study conclusion score) ± SEM
Symptom number is a total number out of 22, symptom severity is a score out of 132

TABLE: III. STUDY CONCLUSION RESULTS FOLLOWING TWO OSTEOPATHIC MANUAL TREATMENTS

Metric	***t***	***df***	***p***
CBF	0.37	21	0.71
CBFV	1.41	21	0.17
IJV (volume)	-0.30	21	0.77
IJV (velocity)	0.45	21	0.66
Symptoms No., (SCAT5)	3.11	15.51	0.007**
Symptom Severity (SCAT5)	3.33	13.15	0.005**

Abbreviations: SCAT5, Sport Concussion Assessment Tool-5th Edition
** denotes significance $p < 0.008$

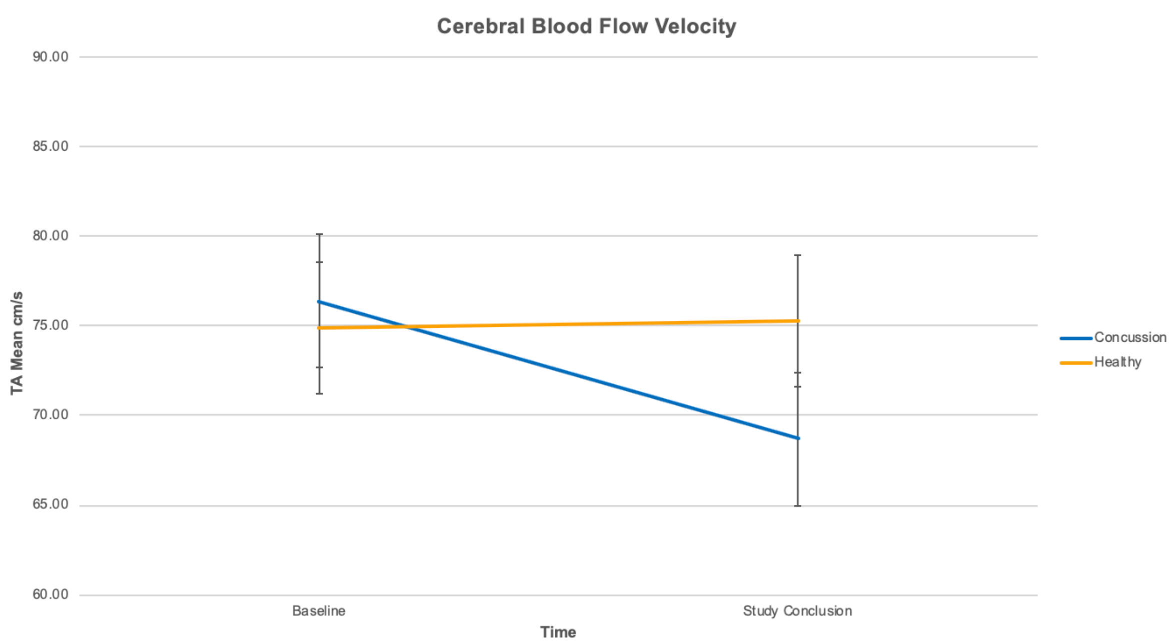
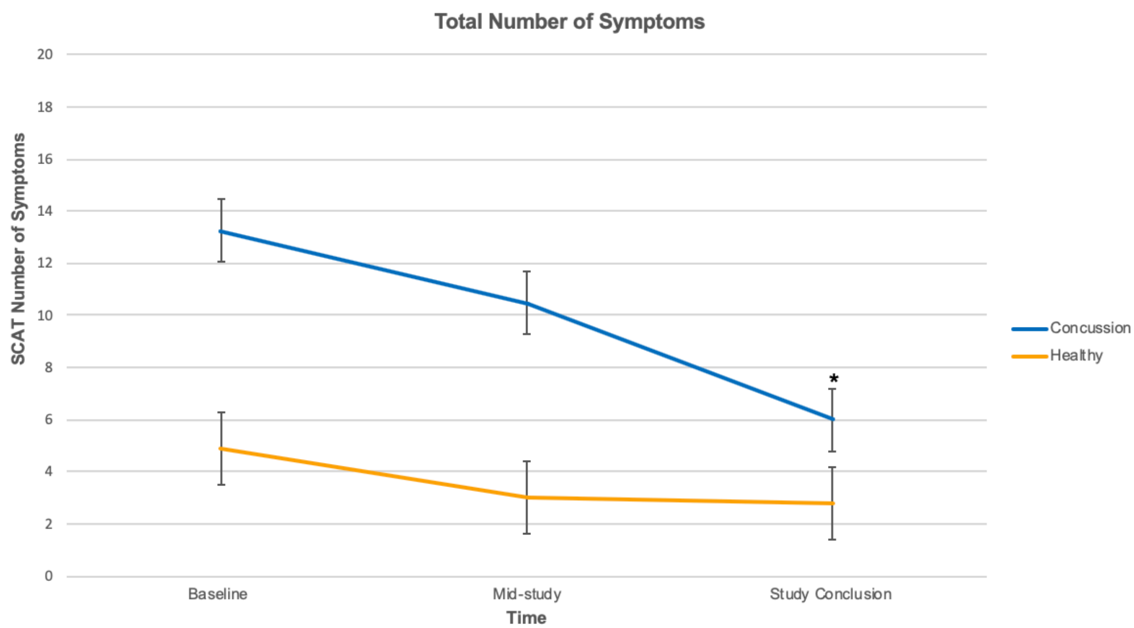


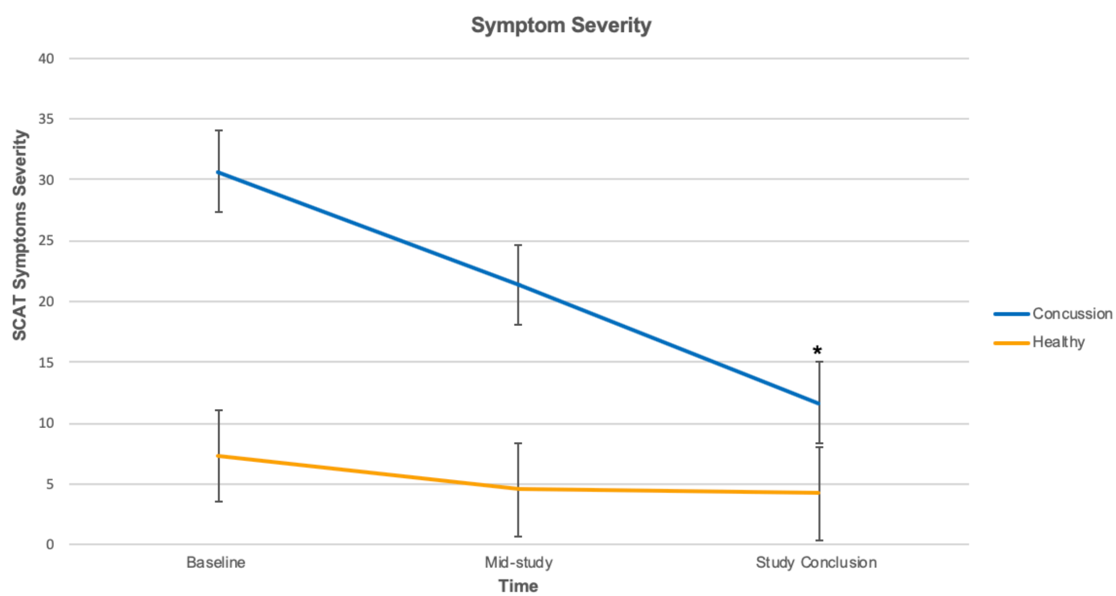
Figure: 4. A trend toward decreased mean CBFV was found between baseline and study conclusion measurements, demonstrating a change in CBFV after manual therapy intervention.

(a)



*Statistically significant $p < 0.008$

(b)



*Statistically significant $p < 0.008$

Figure: 5. A significant change in mean total number of symptoms (a) and mean symptom severity (b) scores as reported on the SCAT5 Symptom Evaluation from baseline to study conclusion. The change is attributed to the manual therapy intervention.

All participants in the concussion group reported a reduction in the total number of symptoms and symptom severity on the SCAT5 Symptom Evaluation. Five of the thirteen concussed participants made a full recovery (total number of symptoms ≤ 2) after two treatment sessions based on normative data from professional rugby and hockey athletes (Fuller, Govind, Tucker, & Raftery, 2018; Hänninen et al., 2016). Descriptive statistics for individual SCAT5 symptoms are outlined in Table IV.

TABLE: IV. MEAN DIFFERENCES AND STANDARD ERRORS FOR INDIVIDUAL SCAT5 SYMPTOMS

Symptom	***Mean Difference (study conclusion – baseline score)***	***Standard Error of Mean Difference (study conclusion – baseline score)***
Headache	-1.00	0.44
Pressure in head	-1.31	0.47
Neck pain	-1.23	0.54
Nausea or vomiting	-0.15	0.00
Dizziness	-0.69	0.24
Blurred vision	-0.31	0.35
Balance problems	0.08	0.21
Sensitivity to light	-1.38	0.37
Sensitivity to noise	-0.92	0.37
Feeling slowed down	-0.69	0.26
Feeling like "in a fog"	-0.69	0.21
"Don't feel right"	-1.46	0.39
Difficulty Concentrating	-1.23	0.44
Difficulty remembering	-1.31	0.46
Fatigue or low energy	-1.31	0.50
Confusion	-0.69	0.31
Drowsiness	-1.23	0.47
More emotional	-0.85	0.37
Irritability	-1.00	0.32
Sadness	-0.31	0.26
Nervous or anxious	-0.38	0.24
Trouble falling asleep	-0.77	0.73

Abbreviations: SCAT5, Sport Concussion Assessment Tool-5th Edition

Discussion

Although the current study was unable to provide statistically significant objective physiological support for OMT as a means of concussion rehabilitation there is support that OMT may decrease symptom burden and severity in a concussed population. These results coupled with a trend toward improved vessel compliance, as seen through decreased CBFV, may provide support that OMT helps to recover CBF function in a concussed population. CBF can adapt to changes in vascular resistance and can recalibrate in response to variations in blood or perfusion pressure making CBF remarkably stable (Strandgaard & Paulson, 1984). This study found a trend towards reduced CBFV in concussed individuals. As such, CBFV shows promise as a measure to monitor changes in physiology in concussed individuals in a clinical setting. Following OMT vessel compliance may be improved. With relatively stable cerebral blood flow volume (CBF) and decreased CBFV (TAMEAN) it can be inferred that vessel diameter is the reason for the observed change in velocity (CBF = TAMEAN x cross-sectional area).

OMT may help to restore torturous blood vessels and turbulent or non-axial flow of blood within the vessels, both which have been sighted as possible reasons for reading discrepancies between MRI and Doppler ultrasound (Ho et al., 2002; Oktar et al., 2006). This finding is important because according to the CISG, all participants in the current study were classified as having persistent symptoms (McCrory et al., 2017). Intervention was not initiated until at minimum ten days post injury, after the point of expected spontaneous resolution of symptoms. Therefore; the change in subjective symptom reporting may be related to intervention.

A previous neuroimaging study provided preliminary results that the SCAT5 symptom severity scale may be associated with CBF, with higher symptoms correlated to increased CBF (Churchill, Hutchison, Graham, et al., 2017). Several concussion studies have found both increased (Churchill, Hutchison, et al., 2017a; Doshi et al., 2015) and decreased CBF (Churchill, Hutchison, et al., 2017a; Lin et al., 2016; Meier et al., 2015; Peng et al., 2016; Wang et al., 2016) following concussion in the acute and subacute phase (ranging from 24 hours to one month). The current study evaluated cerebral hemodynamics at several stages in recovery, eight participants were evaluated between one month and one-year post injury, two participants at 16 days post injury, two participants at 10- to 13-days post injury and one participant at five years post injury. All participants were experiencing post concussion symptoms during baseline data collection and all participants reported improvements throughout the study.

In the acute phase (24- to 48- hours) elevated CBF may be due to cerebral edema (Kors et al., 2001) possibly caused by the ionic flux initiated from trauma (Giza & Hovda, 2014). In the days following, decreased CBF may be due to reductions in blood delivered to the vascular bed (Buxton, 2005) or continued brain metabolism dysfunction (Hadanny & Efrati, 2016). In both situations, improved vessel compliance would be beneficial for symptom recovery. According to Giza and Hovda (2014), headache, photophobia, and phonophobia may be clinically correlated to the rapid ionic flux. Improvements in blood flow and brain metabolism may help to decrease or resolve these symptoms.

The self-reported symptom results of the current study are further supported by Chappell et al. (2015) who found similar results on the effects of OMT on concussion symptom resolution. Following OMT all 22 self-reported symptoms listed on the SCAT2 improved in 26 concussed athletes. It is important to note detailed statistical information was not reported, therefore; the results may be inflated if normality tests were not administered. Furthermore, the current study unlike Chappell et al. (2015), evaluated cerebral hemodynamics in addition to SCAT5 and found a trend toward decreased CBFV in concussed participants post OMT. Together these findings bolster support that OMT may enhance recovery from concussion symptoms and severity of symptoms as well as improve cerebral hemodynamics. As such OMT should be considered as a treatment option for individuals suffering from persistent concussive symptoms (≥10 days).

Osteopathy as a profession is dynamic, inclusive, and patient-centered and should be considered a rehabilitation option for individuals suffering from persistent concussion symptoms (≥10 days). It is important to note we cannot rule out time as a factor as change may be attributed to time since injury. Nonetheless a multi-faceted approach to care is the preferred option for concussion management (Choe & Giza, 2015; Ellis, Leddy, Cordingley, & Willer, 2018; Ellis et al., 2015; McCrory et al., 2017; Pertab et al., 2018; Schneider, 2019; Schneider et al., 2014).

Several rehabilitation strategies have been shown to be effective in concussion management: vestibular therapy (Alsalaheen et al., 2010; Gottshall, 2011; Schneider et al., 2014); physical therapy including physiotherapy and chiropractic (Marshall, Vernon, Leddy, & Baldwin, 2015; Olson, Tunning, & Boesch, 2016; Schneider et al., 2014); graded exercise programs (Gagnon, Galli, Friedman, Grilli, & Iverson, 2009; Leddy, Baker, & Willer, 2016; Leddy, Haider, Ellis, & Willer, 2018; Leddy et al., 2010; Leddy, Wilber, & Willer, 2018; Leddy & Willer, 2013; Marshall et al., 2015; Tan, Meehan, Iverson, & Taylor, 2014); osteopathy (Castillo et al., 2016; Chappell et al., 2015; Guernsey et al., 2016; Hitscherich et al., 2016; Patel & Sabini, 2018); cognitive-behavioural therapy (Eastman & Chang, 2015; Potter & Brown, 2012); hyperbaric oxygen therapy (Boussi-Gross et al., 2013; Hu et al., 2015; Miller et al., 2015); and neuro-optometry (Cohen, 2013; Gallaway, Scheiman, & Mitchell, 2017). Given the complexities of concussion, the numerous brain regions affected, and physiological processes disrupted, it seems logical that an integrated approach be the preferred option.

Despite the promising research in rehabilitation options, most aforementioned studies included varied populations and provided limited support, with the exception of graded exercise programs. Other interventions may include: pharmacological support, education and nutrition; and relaxation and meditation protocols. These topics are beyond the scope of this paper but are worth mentioning.

Limitations

As with many concussion studies, there were a few limitations to the current study. First, the limited sample potentially explains the lack of significant findings. There were large variances in the standard error of means (SEM) and in some cases the error was larger than the means themselves. However, with further recruitment CBFV may become an important physiological measure for concussion research as it pertains to intervention studies.

Second, Doppler ultrasound is operator-dependent, calling into question intra- or inter-rater reliability of the device. Efforts were made to control the operator bias as only one sonographer was employed to record the data. However, we cannot rule out intra-rater reliability. Similarly, only one manual therapist was employed to perform OMT and intra-rater reliability cannot be dismissed. Despite these limitations the study design was selected because Doppler ultrasound is potentially a valuable clinical tool for concussion management as it is readily accessible and recordings can be performed bedside.

Finally, concussion remains a clinical diagnosis; therefore, recruitment of the concussion group was based on diagnoses from several physicians. The definition of concussion and mTBI are often used interchangeably and symptom severity can largely vary between individuals. Only complicated mTBI's show visual anomalies on neuroimaging scans. As a result there may have been large variances between recruited concussion participants.

CONCLUSION

In conclusion, the neuropathology of a concussion is complex; simplistic answers are unlikely to yield satisfactory results. The conclusions made by Iverson hold true today,

> "the literature is large, convoluted, methodologically flawed, and the conclusions drawn frequently go well beyond the empirical data. Experienced clinicians and researchers know that it is extraordinarily difficult to disentangle the many factors that can be related to self-reported symptoms in persons who have sustained remote mTBIs" (Iverson, 2005, p. 307).

As concussion and mTBI are complex by nature, it is reasonable to conclude that so must be the resolution and treatment. As such, a preferred multidisciplinary approach to care is recognized with osteopathy as part of the solution and team.

CHAPTER THREE: DISCUSSION & CONCLUSIONS

DISCUSSION

There is a paucity of concussion rehabilitation research. Based on the findings from this study, future studies should continue to explore the relationship between CBF and CBFV and OMT. A blinded study on the effects of OMT as measured by Doppler ultrasound, could help to eliminate the potential interaction effect of manual therapy on a healthy population. Adults often have unresolved musculoskeletal dysfunctions and typically refrain from seeking help unless they are in pain. Generally, people are not motivated by a proactive approach to health care. Therefore, healthy individuals may not be truly healthy. Efforts should be made to explore CBF measures in the healthy population as well as throughout all phases of a concussion: acute (24-48 hours); subacute (≥48 hours up to 10-14 days), 1-month, 3 months and 1-year post injury. Evaluating CBF at theses specific phases will help to fill a void in the literature regarding CBF changes post injury and allow future research to be replicated. As it remains currently there are large variances surrounding time of data collection.

A study exploring the effects of OMT as measured by ASL and MRI would lend to the discussion about specific ROIs effected by treatment. Although, these measurement tools are not feasible in a clinic setting, significant findings may help to provide support for rehabilitation options. By identifying specific ROIs effected by concussion and relating these findings to aspects of current evaluation tools (ie. SCAT5), manual therapists and rehabilitation experts can develop individualized symptom-specific rehabilitation plans. For example the inferior frontal lobe plays a role in cognitive function, the middle temporal gyri in semantic functions, and the parietal lobe has a critical role in visual and sensory integration (Churchill, Hutchison, et al., 2017b). If there is an understanding of what symptoms correlate with which brain areas therapists may be able to provide more specific rehabilitation options for concussed individuals.

The small sample size in the current study prevented the exploration of sex differences but research suggests differences may exist. Women may be at a greater risk of sustaining a concussion (Covassin, Moran, & Elbin, 2016; Covassin, Swanik, & Sachs, 2003) and take longer to recover once a concussion has been incurred (Covassin, Elbin, Harris, Parker, & Kontos, 2012; Gallagher et al., 2018; Neidecker, Gealt, Luksch, & Weaver, 2017; Stone, Lee, Garrison, Blueitt, & Creed, 2017). Females have been found to report more concussive symptoms and perform worse on visual, and simple and complex reaction time tasks following a concussion (Broshek et al., 2005; Covassin, Elbin, Harris, et al., 2012). In contrast, another study found female athletes to perform better than male athletes on verbal memory and motor processing speed post concussion; these athletes were asymptomatic prior to testing (Covassin, Elbin, Larson, & Kontos, 2012). With limited research into sex differences in concussion recovery and with contradictory results, it is hard to comment whether females fair worse or better than males, but what remains true is sex differences exist.

Cumulative effects of concussion are a topic of current debate. Whether or not multiple concussions effect recovery or create vulnerability for future concussions remains unknown. Caution should be taken when exploring individuals with history of concussion as a group. The initial design for this study included a history of concussion group. Recently Boshra et al. (2019) used electroencephalography (EEG) to evaluate event-related potentials (ERPs), demonstrating that machine learning can detect concussion effects in individuals who last sustained their concussion up to 30 years prior. These results suggest it is possible that lingering concussion symptoms may be present up to years after sustaining the initial injury. Consequently this group was excluded in statistical analysis in an effort to more clearly interpret the effect of OMT on currently diagnosed concussion symptomology.

Additional measurements were collected during this study but not analyzed. Future studies could explore the relationship between concussion and cognitive motor integration (CMI), neck pain and depression. Individuals of all ages and performance levels have shown CMI performance deficits in movement planning, timing and execution post-concussion despite being asymptomatic (Brown, Dalecki, Hughes, Macpherson, & Sergio, 2015; Dalecki, Albines, Macpherson, & Sergio, 2016; Hurtubise, Gorbet, Hamandi, Macpherson, & Sergio, 2016). Attention to cervical spine dysfunction may be important for concussion rehabilitation as cervical strain/whiplash symptoms can mirror concussion symptoms (Hynes & Dickey, 2006; Marshall et al., 2015; Morin, Langevin, & Fait, 2016; Schneider et al., 2014). Depression is the most complex of all; as depression is one of the most common mental health problems in the world. The combination of depression and a mTBI is associated with an extremely high symptom burden and/or increased post-concussion symptoms therefore worthy of exploration (Lange, Iverson, & Rose, 2011; Rapoport, Mccullagh, Streiner, & Feinstein, 2003).

Conclusions

The neuropathology of a concussion is complex; simplistic answers are unlikely to yield satisfactory results. Although this project was unable to provide statistically significant physiological support for osteopathic manual therapy (OMT) and concussion rehabilitation, it did provide significant support that OMT can help to decrease symptom burden and severity in a concussed population and presented support for its effect on CBF through blood vessel compliance. Thus, OMT is considered an effective rehabilitation option for individuals experiencing persistent concussion symptoms (≥ 10 days).

Overall, this study provides preliminary support that OMT may help to improve CBFV. The results support OMT therapy as a safe and viable rehabilitation option for concussion. As concussion and mTBI are complex by nature, it is reasonable to conclude that so must be the resolution and treatment. As such, a preferred multidisciplinary approach to care is recognized with osteopathy as part of the solution and team.

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APPENDIX A: HEALTH QUESTIONNAIRE

Health Questionnaire

Step 1: Athlete Background – SCAT5 (included)

Pretest Intake Questionnaire – BrDI, HRV and Doppler study

(The information received will remain confidential)

ID: ___________________________________ **Date of Test:** ________________________________

Age: ________ **Height**: _________ **Weight:** _________ **Neck Circumference:** ______ **DOB:** _____________

Dominant Hand: LEFT or RIGHT or BOTH **Sex**: Male or Female or Other

Level of Education: ________________________ **Work Full Time / Part Time / Neither**:___________

Ethnicity: __________________________________ **Occupation**: ________________________________

Sport(s) Played (recreational or competitive): ____

How long did you play your sport(s): ____

1. Do you **currently** have a concussion? (an impact to the head which MAY have resulted in: headaches, loss of consciousness, confusion, amnesia, dizziness, nausea, etc)

   YES or NO (if answer is NO please proceed to question 2)

   a) Date of concussion: ________________________________

   b) Did you lose consciousness? ___________ For how long? ________________________

   c) Please list any current signs and symptoms:

   ____

   ____

2. Have you **previously** had any concussions (an impact to the head which MAY have resulted in: headaches, loss of consciousness, confusion, amnesia, dizziness, nausea, etc)?

   YES or NO (if answer is NO please proceed to question 3)

   a) How many? ____________

   b) Did you lose consciousness? ___________ For how long? ________________________

   c) Date(s) and time out before returning to play:

   ____

   d) Did you receive treatment for your concussion? YES or NO

   Type of treatment received:

____

3. Have you ever been hospitalized for a head injury? YES or NO

4. Current medications? If yes, please list: ____

5. Do you smoke? YES or NO

a) Do you smoke: Cigarettes, Cannabis, Both or Other: _________________________

b) How often do you smoke the above mentioned substance(s) per day, week or month?

____

6. In the last 2 hours have you consumed/inhaled

a. any stimulants such as caffeine (coffee) or nicotine (smoking)? YES or NO

b. any depressants such as marijuana or alcohol? YES or NO

7. Have you been diagnosed with any neurological disorders? YES or NO

What disorder? ____

8. Have you been diagnosed with any of the following:

Disorder	YES	NO	Diagnosis
Diabetes			
Cancer			
Autoimmune Disorder (Rheumatoid Arthritis, Lupus)			
Cerebrovascular Disease (Stroke, Aneurism)			
Cardiovascular Disease (Heart attack or failure)			
Hypertension			
Dementia			
Headache Disorder or Migraines			
Learning Disability or Dyslexia			
ADD or ADHD			
Depression, Anxiety or other Psychiatric Disorders			

9. Has anyone in your family been diagnosed with any of the following:

Disorder	YES	NO	Diagnosis
Diabetes			
Cancer			
Autoimmune Disorder (Rheumatoid Arthritis, Lupus)			
Cerebrovascular Disease (Stroke, Aneurism)			
Cardiovascular Disease (Heart attack, Heart failure)			
Hypertension			
Dementia			

10. Do you have a computer (YES or NO) or a tablet (YES or NO) at home?

How often do you use your computer? (all the time / often / sometimes / rarely / never)

How often do you use your tablet? (all the time / often / sometimes / rarely / never)

11. Do you do puzzles? YES or NO (all the time / often / sometimes / rarely / never)

12. Do you play video games? YES or NO (all the time / often / sometimes / rarely / never)

a) What type of games do you typically play? ACTION (time pressure) or NON-ACTION

b) How would you rate your skill compared to your peers? (Low / Intermediate / High)

THE FOLLOWING IS A LIST OF ACTIVITIES THAT PEOPLE MAY PARTICIPATE IN. PLEASE INDICATE THE FREQUENCY (IN DAYS PER WEEK) THAT YOU TYPICALLY PARTICIPATE IN THESE ACTIVITES.

FOR EACH ITEM CHOOSE FROM ONE OF THE FOLLOWING ALTERNATIVES:

	NEVER	RARELY (1 DAY/ WEEK)	SOMETIMES (2 DAYS/ WEEK)	FAIRLY OFTEN (3-4 DAYS/ WEEK)	VERY OFTEN (5-7 DAYS/ WEEK)
	0	1	2	3	4
WATCHING TV OR MOVIES	0	1	2	3	4
READING	0	1	2	3	4
SOCIALIZING (E.G. PLAYING CARDS, TALKING TO FRIENDS, ETC.)	0	1	2	3	4
PLAYING REC SPORTS	0	1	2	3	4
PLAYING COMPETITIVE SPORTS	0	1	2	3	4
PLAYING VIDEO/ COMPUTER GAMES	0	1	2	3	4
WALKING (AT LEAST 25 MINUTES)	0	1	2	3	4
LISTENING TO MUSIC	0	1	2	3	4

EXERCISING AT A GYM	0	1	2	3	4
DOING NON-LABOUR WORK (PAID OR VOLUNTEER)	0	1	2	3	4
DOING LABOUR WORK (E.G. LANDSCAPING SHOVELING, PAINTING, ETC. PAID OR VOLUNTEER)	0	1	2	3	4
RUNNING/JOGGING	0	1	2	3	4
13. PUZZLES, ARTS & CRAFTS (E.G. KNITTING, CROSSWORDS, ETC.)	0	1	2	3	4

LAST QUESTION! FEMALES ONLY

1. Menstrual Cycle:
   a. Flow: Light or Regular or Heavy
   b. Length of Cycle: ____________
   c. Contraceptive Use: Birth Control or IUD or Other _________
   d. Peri-menopausal or Post- menopausal* or Not Applicable

*post- menopausal is defined as having no period for the past 12 months

   e. Circle all that apply: PCOS, Endometriosis, Fibroids, Cysts

APPENDIX B: SCAT5 – SYMPTOM EVALUATION

STEP 2: Symptom Evaluation – SCAT5

You should score yourself on the following symptoms, based on how you feel now.

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
Pressure in head	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred Vision	0	1	2	3	4	5	6
Balance Problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like “in a fog”	0	1	2	3	4	5	6
“Don’t feel right”	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6
Trouble falling asleep (if applicable)	0	1	2	3	4	5	6
Total number of symptoms				Out of 22			
Symptom severity				Out of 132			
Do your symptoms get worse with physical activity?						Y	N
Do your symptoms get worse with mental activity?						Y	N
If 100% is feeling perfectly normal, what percent do you feel?							

If not 100%, why? ____

____

____

____

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APPENDIX C: CENTER FOR EPIDEMIOLOGIC STUDIES DEPRESSION SCALE – REVISED (CESD-R)

Center for Epidemiologic Studies Depression Scale – Revised (CESD-R)

Below is a list of the ways you might have felt or behaved. Please check the boxes to tell me how often you have felt this way in the past week or so.	Last Week				Nearly every day for 2 weeks
	Not at all *or* Less than 1 day	1 - 2 days	3 - 4 days	5 - 7 days	
My appetite was poor.	0	1	2	3	4
I could not shake off the blues.	0	1	2	3	4
I had trouble keeping my mind on what I was doing.	0	1	2	3	4
I felt depressed.	0	1	2	3	4
My sleep was restless.	0	1	2	3	4
I felt sad.	0	1	2	3	4
I could not get going.	0	1	2	3	4
Nothing made me happy.	0	1	2	3	4
I felt like a bad person.	0	1	2	3	4
I lost interest in my usual activities.	0	1	2	3	4
I slept much more than usual.	0	1	2	3	4
I felt like I was moving too slowly.	0	1	2	3	4
I felt fidgety.	0	1	2	3	4
I wished I were dead.	0	1	2	3	4
I wanted to hurt myself.	0	1	2	3	4
I was tired all the time.	0	1	2	3	4
I did not like myself.	0	1	2	3	4
I lost a lot of weight without trying to.	0	1	2	3	4
I had a lot of trouble getting to sleep.	0	1	2	3	4
I could not focus on the important things.	0	1	2	3	4

REFERENCE: Eaton, W. W., Smith, C., Ybarra, M., Muntaner, C., Tien, A. (2004). Center for Epidemiologic Studies Depression Scale: review and revision (CESD and CESD-R). In ME Maruish (Ed.). *The Use of Psychological Testing for Treatment Planning and Outcomes Assessment* (3rd Ed.), Volume 3: Instruments for Adults, pp. 363-377. Mahwah, NJ: Lawrence Erlbaum.

APPENDIX D: NECK DISABILITY INDEX (NDI)

NECK DISABILITY INDEX

THIS QUESTIONNAIRE IS DESIGNED TO HELP US BETTER UNDERSTAND HOW YOUR NECK PAIN AFFECTS YOUR ABILITY TO MANAGE EVERYDAY -LIFE ACTIVITIES. PLEASE MARK IN EACH SECTION THE **ONE BOX** THAT APPLIES TO YOU. ALTHOUGH YOU MAY CONSIDER THAT TWO OF THE STATEMENTS IN ANY ONE SECTION RELATE TO YOU, PLEASE MARK THE BOX THAT **MOST CLOSELY** DESCRIBES YOUR PRESENT -DAY SITUATION.

SECTION 1 - PAIN INTENSITY

- ❑ I have no pain at the moment.
- ❑ The pain is very mild at the moment.
- ❑ The pain is moderate at the moment.
- ❑ The pain is fairly severe at the moment.
- ❑ The pain is very severe at the moment.
- ❑ The pain is the worst imaginable at the moment.

SECTION 2 - PERSONAL CARE

- ❑ I can look after myself normally without causing extra pain.
- ❑ I can look after myself normally, but it causes extra pain.
- ❑ It is painful to look after myself, and I am slow and careful.
- ❑ I need some help but manage most of my personal care.
- ❑ I need help every day in most aspects of self -care.
- ❑ I do not get dressed. I wash with difficulty and stay in bed.

SECTION 3 – LIFTING

- ❑ I can lift heavy weights without causing extra pain.
- ❑ I can lift heavy weights, but it gives me extra pain.
- ❑ Pain prevents me from lifting heavy weights off the floor but I can manage if items are conveniently positioned, ie. on a table.
- ❑ Pain prevents me from lifting heavy weights, but I can manage light weights if they are conveniently positioned.
- ❑ I can lift only very light weights.
- ❑ I cannot lift or carry anything at all.

SECTION 4 – WORK

- ❑ I can do as much work as I want.
- ❑ I can only do my usual work, but no more.
- ❑ I can do most of my usual work, but no more.
- ❑ I can't do my usual work.
- ❑ I can hardly do any work at all.
- ❑ I can't do any work at all.

SECTION 5 – HEADACHES

- ❑ I have no headaches at all.
- ❑ I have slight headaches that come infrequently.
- ❑ I have moderate headaches that come infrequently.
- ❑ I have moderate headaches that come frequently.
- ❑ I have severe headaches that come frequently.
- ❑ I have headaches almost all the time.

SECTION 6 – CONCENTRATION

- ❑ I can concentrate fully without difficulty.
- ❑ I can concentrate fully with slight difficulty.
- ❑ I have a fair degree of difficulty concentrating.
- ❑ I have a lot of difficulty concentrating.
- ❑ I have a great deal of difficulty concentrating.
- ❑ I can't concentrate at all.

SECTION 7 – SLEEPING

- ❑ I have no trouble sleeping.
- ❑ My sleep is slightly disturbed for less than 1 hour.
- ❑ My sleep is mildly disturbed for up to 1-2 hours.
- ❑ My sleep is moderately disturbed for up to 2-3 hours.
- ❑ My sleep is greatly disturbed for up to 3-5 hours.
- ❑ My sleep is completely disturbed for up to 5-7 hours.

SECTION 8 – DRIVING

- ❑ I can drive my car without neck pain.
- ❑ I can drive as long as I want with slight neck pain.
- ❑ I can drive as long as I want with moderate neck pain.
- ❑ I can't drive as long as I want because of moderate neck pain.
- ❑ I can hardly drive at all because of severe neck pain.
- ❑ I can't drive my care at all because of neck pain.

SECTION 9 – READING

- ❑ I can read as much as I want with no neck pain.
- ❑ I can read as much as I want with slight neck pain.
- ❑ I can read as much as I want with moderate neck pain.
- ❑ I can't read as much as I want because of moderate neck pain.
- ❑ I can't read as much as I want because of severe neck pain.
- ❑ I can't read at all.

SECTION 10 – RECREATION

- ❑ I have no neck pain during all recreational activities.
- ❑ I have some neck pain with all recreational activities.
- ❑ I have some neck pain with a few recreational activities.
- ❑ I have neck pain with most recreational activities.
- ❑ I can hardly do recreational activities due to neck pain.
- ❑ I can't do any recreational activities due to neck pain.

PATIENT NAME ____ DATE _______________

SCORE ___________ [50] BENCHMARK -5 = ___________

Appendix D: Sport Concussion Assessment Tool 5th Edition

3

STEP 3: COGNITIVE SCREENING

Standardised Assessment of Concussion (SAC)[4]

ORIENTATION

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1
Orientation score		of 5

IMMEDIATE MEMORY

The Immediate Memory component can be completed using the traditional 5-word per trial list or optionally using 10-words per trial to minimise any ceiling effect. All 3 trials must be administered irrespective of the number correct on the first trial. Administer at the rate of one word per second.

Please choose EITHER the 5 or 10 word list groups and circle the specific word list chosen for this test.

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. For 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.

List	Alternate 5 word lists					Score (of 5) Trial 1	Trial 2	Trial 3
A	Finger	Penny	Blanket	Lemon	Insect			
B	Candle	Paper	Sugar	Sandwich	Wagon			
C	Baby	Monkey	Perfume	Sunset	Iron			
D	Elbow	Apple	Carpet	Saddle	Bubble			
E	Jacket	Arrow	Pepper	Cotton	Movie			
F	Dollar	Honey	Mirror	Saddle	Anchor			
					Immediate Memory Score	of 15		
					Time that last trial was completed			

List	Alternate 10 word lists					Score (of 10) Trial 1	Trial 2	Trial 3
G	Finger	Penny	Blanket	Lemon	Insect			
	Candle	Paper	Sugar	Sandwich	Wagon			
H	Baby	Monkey	Perfume	Sunset	Iron			
	Elbow	Apple	Carpet	Saddle	Bubble			
I	Jacket	Arrow	Pepper	Cotton	Movie			
	Dollar	Honey	Mirror	Saddle	Anchor			
					Immediate Memory Score	of 30		
					Time that last trial was completed			

Name: ____________________
DOB: ____________________
Address: ____________________
ID number: ____________________
Examiner: ____________________
Date: ____________________

CONCENTRATION

DIGITS BACKWARDS

Please circle the Digit list chosen (A, B, C, D, E, F). Administer at the rate of one digit per second reading DOWN the selected column.

I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.

Concentration Number Lists (circle one)					
List A	List B	List C			
4-9-3	5-2-6	1-4-2	Y	N	0
6-2-9	4-1-5	6-5-8	Y	N	1
3-8-1-4	1-7-9-5	6-8-3-1	Y	N	0
3-2-7-9	4-9-6-8	3-4-8-1	Y	N	1
6-2-9-7-1	4-8-5-2-7	4-9-1-5-3	Y	N	0
1-5-2-8-6	6-1-8-4-3	6-8-2-5-1	Y	N	1
7-1-8-4-6-2	8-3-1-9-6-4	3-7-6-5-1-9	Y	N	0
5-3-9-1-4-8	7-2-4-8-5-6	9-2-6-5-1-4	Y	N	1
List D	List E	List F			
7-8-2	3-8-2	2-7-1	Y	N	0
9-2-6	5-1-8	4-7-9	Y	N	1
4-1-8-3	2-7-9-3	1-6-8-3	Y	N	0
9-7-2-3	2-1-6-9	3-9-2-4	Y	N	1
1-7-9-2-6	4-1-8-6-9	2-4-7-5-8	Y	N	0
4-1-7-5-2	9-4-1-7-5	8-3-9-6-4	Y	N	1
2-6-4-8-1-7	6-9-7-3-8-2	5-8-6-2-4-9	Y	N	0
8-4-1-9-3-5	4-2-7-9-3-8	3-1-7-8-2-6	Y	N	1
		Digits Score:			of 4

MONTHS IN REVERSE ORDER

Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November. Go ahead.

Dec - Nov - Oct - Sept - Aug - Jul - Jun - May - Apr - Mar - Feb - Jan	0 1
Months Score	of 1
Concentration Total Score (Digits + Months)	of 5

4

STEP 4: NEUROLOGICAL SCREEN

See the instruction sheet (page 7) for details of test administration and scoring of the tests.

Can the patient read aloud (e.g. symptom check-list) and follow instructions without difficulty?	Y	N
Does the patient have a full range of pain-free PASSIVE cervical spine movement?	Y	N
Without moving their head or neck, can the patient look side-to-side and up-and-down without double vision?	Y	N
Can the patient perform the finger nose coordination test normally?	Y	N
Can the patient perform tandem gait normally?	Y	N

BALANCE EXAMINATION

Modified Balance Error Scoring System (mBESS) testing[5]

Which foot was tested (i.e. which is the non-dominant foot) ☐ Left ☐ Right

Testing surface (hard floor, field, etc.) ______

Footwear (shoes, barefoot, braces, tape, etc.) ______

Condition	Errors
Double leg stance	of 10
Single leg stance (non-dominant foot)	of 10
Tandem stance (non-dominant foot at the back)	of 10
Total Errors	of 30

Name: ______
DOB: ______
Address: ______
ID number: ______
Examiner: ______
Date: ______

5

STEP 5: DELAYED RECALL:

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section. Score 1 pt. for each correct response.

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.

Time Started ______

Please record each word correctly recalled. Total score equals number of words recalled.

______
______
______

Total number of words recalled accurately: of 5 or of 10

6

STEP 6: DECISION

Domain	Date & time of assessment:		
Symptom number (of 22)			
Symptom severity score (of 132)			
Orientation (of 5)			
Immediate memory	of 15 of 30	of 15 of 30	of 15 of 30
Concentration (of 5)			
Neuro exam	Normal Abnormal	Normal Abnormal	Normal Abnormal
Balance errors (of 30)			
Delayed Recall	of 5 of 10	of 5 of 10	of 5 of 10

Date and time of injury: ______

If the athlete is known to you prior to their injury, are they different from their usual self?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**
(If different, describe why in the clinical notes section)

Concussion Diagnosed?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

If re-testing, has the athlete improved?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

I am a physician or licensed healthcare professional and I have personally administered or supervised the administration of this SCAT5.

Signature: ______
Name: ______
Title: ______
Registration number (if applicable): ______
Date: ______

SCORING ON THE SCAT5 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.