The Effects of Neurocognitive and Physical Tasks on Breathing and Executive Functioning in Healthy Versus Concussed Canadian Military Members

Jordan B. Bedel

Supervisor: Dr. Paolo Sanzo

Committee Members Dr. Ian Newhouse and Dr. Carlos Zerpa

Lakehead University

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SCHOOL OF KINESIOLOGY

LAKEHEAD UNIVERSITY

THUNDER BAY, ONTARIO, CANADA

Abstract

When on active-duty, Canadian Armed Forces (CAF) members may be exposed to dangers and repetitive sub-concussive impacts such as explosive devices, loud gunfire, and hand-to-hand physical combat. These individuals are at constant risk of experiencing a variety of injuries including concussions. During a concussion, damage may occur to neural and vascular tissues that can cause physiological changes in the brain. Abnormal breathing patterns may emerge, if there is damage to the brainstem or middle cerebral artery, which may reduce blood flow to the thalamus and brainstem and the respiratory control centres. Therefore, the purpose of this study was to examine differences between healthy and concussed military members when completing a neurocognitive and physical task on measures of breathing function.

Two groups were recruited including a concussed and a healthy group. Participants included males and females between the ages of 18-59 years who were active military members. Healthy military members were required to have been absent of a concussion within the last 24 months. The concussed military members were required to have been diagnosed with at least 1 concussion by a medical professional within the previous 2-12 months. All participants had to have been absent of any debilitating injury or condition which would prevent them from safely engaging in physical activity or any other neurological disorder that have may altered their results and performance. Although a concussion is classified as a neurological disorder, the participant must not have had any other neurological disorders. All participants were also required to be absent of any previous existing respiratory disorders.

Data collection consisted of a single session, lasting approximately 45-60 minutes. The participants began by completing the Nijmegen Questionnaire, a 16-item self-report questionnaire designed to assess an individual's breathing patterns. The CapnoTrainer® capnography breath analyzer was then connected and calibrated to a laptop. Participants were fitted with a single-use nasal cannula that was worn throughout the entire data collection process. The ImPACT® neurocognitive test was completed in a quiet, well-lit room, and void of any distractions. The test measured the different dimensions of executive functioning including visual and verbal memory, working memory, processing speed, visual-motor skills, and reaction time. The CapnoTrainer® was used to record respiratory rate (RR) and end-tidal carbon dioxide levels ($ETCO_2$) collected across two tasks including a neurocognitive task and a physical task. The ImPACT®, is a commonly used computerized test designed to measure dimensions of neurocognitive and executive functioning. The physical task involved participants walking on a treadmill under two different walking speeds (4.8-5.5 km/h and then 6.0-6.9 km/h). Each 3-minute walking trial was completed at an incline of .5% and followed by a 2-minute rest break. Participants were equipped with a 20 kg weighted vest during the physical task to simulate the basic physical requirements for all military members.

Two groups (healthy versus concussed) X three conditions (physical task at normal speed, physical task at 25% higher speed, and neurocognitive task) mixed factorial ANOVAs were conducted on measures of $ETCO_2$ levels and RR, respectively. An independent t-test was also conducted to compare the means of the executive functioning scores between healthy versus concussed military members. The two-way mixed factorial ANOVA revealed no statistically significant interaction effect between the two groups (healthy and concussed military members) and the three tasks (physical task at normal speed, physical task at 25% higher speed, and neurocognitive task) on measures of RR and $ETCO_2$. Both concussed and healthy military members produced similar mean RR and $ETCO_2$ values for the physical and neurocognitive tasks. Independent-samples t-tests were conducted to examine differences in executive function scores between concussed and healthy military members. The results did not reveal a statistically significant difference between concussed and healthy participants for verbal memory scores, visual memory, visual motor speed, reaction time, or impulse control.

The results of the present study, indicate that there were no statistically significant differences between healthy and concussed military members on executive functioning scores, RR, and $ETCO_2$ when completing physical and neurocognitive tasks. The results of this study did, however, showed a slight trend indicating elevated RR and $ETCO_2$ values in the concussed group across both physical and neurocognitive tasks. Although the outcomes of this study do not suggest concussive injuries influence breathing function in Canadian military members, it is important to continue this research. We as a country and a community of researchers should be contributing time and resources to providing the proper attention to these areas to ensure the CAF members are able to do their job the most effective and safest way possible.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AAN- American Academy of Neurology

ANS- Autonomic nervous system

CAF- Canadian Armed Forces

CANSOFCOM-Canadian Special Operations Forces Command

CO$_2$ – Carbon dioxide

CTE- Chronic traumatic encephalopathy

ETCO$_2$ - End-tidal carbon dioxide

FORCE- Fitness for operational requirements of Canadian Armed Forces employment

GSC- Glasgow Coma Scale

ImPACT®- Immediate Post-Concussion Assessment and Cognitive Testing®

HR- Heart rate

HRV- Heart rate variability

HVS- Hyperventilation syndrome

LOC- Loss of consciousness

mTBI- Mild traumatic brain injury

NCAA- National Collegiate Athletic Association

NQ- Nijmegen questionnaire

MV- Minute ventilation

O$_2$- Oxygen

PCSS- Post-concussion symptoms scale

PPCO$_2$- Partial pressure of CO$_2$

PPCS- Persistent post-concussion symptoms

PT- Physical therapy

REB- Research Ethics Board

RR- Respiratory rate

SCAT 5- The Sport Concussion Assessment Tool 5th edition

SIS- Second impact syndrome

SNS- Sympathetic nervous system

TBI- Traumatic brain injury

Chapter 1

Introduction

Recently, the media has been drawn to advocates such as Nick Buoniconti and Harry Carson, former players in the National Football League, as well as Sidney Crosby and Dan Carrillo from the National Hockey League regarding the severity of sport-related concussions. These individuals have spoken out about the dangers of repetitive concussive injuries. Despite the large amount of attention that has been brought to concussive injuries recently, concussions have always been present in the workplace, sport participation, and regular activities of daily living.

The popularity on the topic of concussions has, however, sparked an interest from a research perspective, which has led to the discovery of two serious risks that may result from repetitive brain injuries (Musumeci et al., 2019). The two severe and potentially fatal consequences are known as second impact syndrome (SIS) and chronic traumatic encephalopathy (CTE; Williamson & Goodman, 2006). After an initial concussion, the brain goes through a period of metabolic vulnerability where SIS can occur. If an individual is exposed to a second brain injury within this time frame it could in rare cases cause severely altered blood flow leading to swelling in the brain that could result in catastrophic neurological injury and even death (May et al., 2022; Musumeci et al., 2019).

Chronic traumatic encephalopathy has become a well-known issue in retired athletes and military members who have sustained multiple concussions throughout their careers (Bieniek et al., 2015). A high number of concussions has been linked to progressive neurodegeneration that causes a significant loss of neurocognitive functioning, further evolving into dementia (Bieniek et al., 2015; Musumeci et al., 2019). Furthermore, there has been an increase in young amateur and professional athletes suffering from mental illness and committing suicide, which have been linked to CTE pathology in post-mortem examinations (Bieniek et al., 2015). It has also been identified that it is common for a concussion to be left unreported in sport and work-related scenarios due to the low perceived risk (Joyce et al., 2015). Underreporting is largely due to the lack of knowledge or understanding within the general population and health care system regarding the signs, symptoms, and physiological effects of concussion (Joyce et al., 2015). Returning to play, school, or work prior to recovery can, although relatively rare, lead to serious consequences such as SIS and in extreme cases, even death (Williamson & Goodman, 2006). Unfortunately, it is common for the general population to avoid seeking medical assistance as the symptoms of concussion often seem manageable. Wolf and Fast (2017) identified that athletic trainers are more likely to suggest return to play for an athlete based on self-rated symptoms rather than previous executive functioning status achieved using the Immediate Post-Concussion Assessment and Cognitive Testing® (ImPACT®). This suggests that there may be dangerous misinformation within medical professionals, athletes, coaches, and parents, warranting the education of the public on the severity of a brain injury such as a concussion. This lack of information may put individuals at risk and result in increased symptom duration and delayed recovery times. Therefore, it is of the uppermost importance to understand what a concussion is and how it may affect the human body.

A concussion is a form of a mild traumatic brain injury (mTBI), which affects approximately 42 million individuals worldwide each year (Musumeci et al., 2019). This injury is defined as a traumatically induced transient disturbance in brain function that occurs because of external forces of varying intensities to the head, neck, and/or body (Musumeci et al., 2019). Concussive injuries are largely prevalent within the sport participation, military personnel, following motor vehicle accidents, and as a result of falls among the elderly (Tator, 2013; Van

Pelt et al., 2019). Directly after and in the days following a brain injury, neural axonal shearing and stretching occurs. Shearing and stretching of the brain's connective fibers (axons) occur as the brain rotates and shifts within the skull as the initial injury transpires (Giza & Hovda, 2014). An individual with a concussion may immediately present with symptoms such as confusion, disorientation, loss of consciousness (LOC), or more severe neurological abnormalities including seizures and/or damaged tissue in the brain (Gardner & Yaffe, 2015). A concussion to produce a wide variety of symptoms is due to the structures of the brain that may be impaired based on the mechanism and location of the injury (Mccrory et al., 2017).

Treating a concussion typically incorporates a brief period of physical and cognitive rest, followed by a gradual increase in activity, along with consistent check-ins until medically cleared (May et al., 2020; Schneider, 2017). The use of diagnostic imaging, return to work, sport, and play guidelines, along with the identification of the symptoms and subcategories that the injury falls under can lead to the development of more individualized treatment plans (Quatman-Yates et al., 2020). Some individuals, for example, may require specialized treatment if there is significant damage that results in cognitive, auditory, or ocular motor impairments (Quatman-Yates et al., 2020).

Despite the extensive number of symptoms and side effects an individual may experience when suffering from a concussion, breathing dysfunctions and abnormalities are not often listed. A concussion can impact any individual and seriously affect daily brain function depending on the location of the injury. During a concussive injury, the damage that occurs to the neural and vascular tissues causes physiological changes to occur in the brain resulting in the presentation of signs or symptoms related to the functions of that respective area of the brain (Giza & Hovda, 2014). If damage to the brainstem or middle cerebral artery occurs, blood flow to the thalamus, brainstem, and the respiratory control centres may be restricted (Ikeda et al., 2017). These blood flow restrictions might result in abnormal and dysfunctional breathing patterns which lead to respiratory distress. These barriers greatly affect an individual's ability to perform physical activity, sport participation, and effectively engage in a physically demanding career (Ikeda et al., 2017).

The process of breathing relies on the responsibilities and functions of the upper and lower respiratory tracts, a vast collection of muscles within the chest wall, the medulla oblongata, and the pons to permit the movement, collection, and expulsion of gases (Tortora & Nielsen, 2014c). During inhalation, air travels through the upper respiratory tract through the trachea and is pulled into the lungs, reaching the alveoli and pulmonary capillaries where the filtered exchange between oxygen (O_2) and carbon dioxide (CO_2) takes place (Tortora & Nielsen, 2014c). This process produces a balance between the O_2 and CO_2. Carbon dioxide is a waste by-product of cellular respiration, where it is removed through expiration when glucose and O_2 are used to form adenosine triphosphate (ATP; Patel et al., 2021).

The human body requires O_2 to survive and after it is absorbed through the processes in the lungs it is transported to the cells, organs, and tissues in the body via the blood stream (Sarkar et al., 2017). If the human body is deprived of O_2 for several minutes' hypoxia develops and death will occur to the brain followed by the entire body due to complete organ failure (Sarkar et al., 2017). Breathing mechanisms in individuals who have suffered a concussion may be an area of interest in the process of properly diagnosing, treating, and understanding why some individuals go on to develop long-lasting and chronic symptoms (Siedlecki et al., 2018).

There are many factors that have been proven to alter breathing patterns including feelings of anxiety/anxiety disorders, heart failure, and brain injuries, among others (Whited & Graham, 2021). Therefore, monitoring breathing measures is a useful tool in the identification of dysfunctions and other potential health issues. Breathing measures provide important information regarding respiratory patterns and behaviours, metabolism, and pulmonary function (McLaughlin, 2014). Partial pressure of CO_2 ($PPCO_2$) is a representative measure for the balance of CO_2 production and elimination in the human body (McLaughlin, 2014). This measure is known as the current gold standard, however, since CO_2 values change on a breath-by-breath basis, this invasive and time-consuming test ultimately limits detections of poor breathing behaviours (McLaughlin, 2014). An alternative to $PPCO_2$ is a portable capnography breath analyzer that is used to measure the number of breathes per minute (respiratory rate; RR) and the peak CO_2 at the end of an exhaled breath called end-tidal CO_2 ($ETCO_2$; McLaughlin et al., 2011). There is a strong correlation between $PPCO_2$ and $ETCO_2$ measures, therefore, making measures of this sort more accessible to a wider population (Richardson, 2016). Capnography measurements indicate the effectiveness of the blood to carry CO_2 back to the lungs and exhale it. These measures can act as a representation of the physiological processes that may identify if any deficits in RR or $ETCO_2$ (i.e., abnormally high or low values) are present (Richardson et al., 2016).

Siedlecki et al. (2018) identified significant differences between $ETCO_2$ in individuals with persistent post-concussion symptoms (PPCS). The research suggested that individuals experiencing concussion symptoms for an extended period may have developed altered breathing patterns at rest. It was proposed that the altered breathing patterns may have occurred due to the trauma sustained during the concussion. Similarly, Snyder et al. (2021) conducted a pilot study that examined cardiorespiratory functioning in youth with PPCS. Snyder et al. (2021) utilized $ETCO_2$, RR, heart rate (HR), and oxygen saturation (SaO_2) to identify if cardiorespiratory dysfunctions were present while breathing normally in a seated position. This study identified significantly lower $ETCO_2$ measures in participants with PPCS compared to controls as well as increased variability in PR. End-tidal CO_2 levels indicate the effectiveness of the blood to carry the CO_2 back to the lungs to be exhaled. Therefore, $ETCO_2$ measures reflect circulation, pulmonary blood flow and cardiac functions, and ventilation, the ability of the lungs to exhale it. (Richardson, 2016). When $ETCO_2$ values are low, it could suggest inadequate cardiac output, cardiac dysfunction, and or a pulmonary dysfunction (Richardson, 2016). The researchers suggested that individuals who have suffered from a concussion and are experiencing PPCS may have a more difficult time processing and removing CO_2 in their exhaled breath than their non-concussed counterparts. Both Siedlecki et al. (2018) and Snyder et al. (2021) concluded that more research is required to further evaluate breathing patterns in individuals with PPCS.

Many studies have shown that breathing dysfunctions such as agonal breathing (i.e., slow, shallow, and irregular breaths) have been linked to certain types of brain injuries (i.e., anoxic; Whited & Graham, 2021). A concussion can affect many different structures in the brain, if certain structures like the medulla oblongata or pons are injured then respiratory abnormalities or dysfunctions may occur. Breathing abnormalities and dysfunctions can lead to poor gas exchange causing abnormal levels of O_2 and CO_2 in the blood and lungs (Patwa & Shah, 2015). The gas exchange leading to O_2, and CO_2 balance is one of the most important functions that the human body performs. Every structure and organ in the human body requires O_2 to survive and effectively function (Patwa & Shah, 2015). Therefore, if respiratory abnormalities or dysfunctions are present in military members who have had a concussion within the past 2-12 months, the ability to perform daily living activities and advanced career related activities (i.e., physical activity, executive functioning tasks) may be negatively affected. If so, it is important to address this from a diagnostic and treatment perspective. The current literature identifying the risk and prevalence of concussion within the military, however, lacks the component investigating potential breathing abnormalities. This study was one of few that measured executive functioning scores, $ETCO_2$, and RR when completing tasks that mimic day to day cognitive and physical efforts in military members. The significance of this study's results will contribute to limited literature that explores the possibility that abnormal or dysfunctional breathing patterns may exist in individuals who have previously suffered a concussion and are part of Canada's military forces. Therefore, further research is warranted, due to the prevalence of brain injuries that occur during training and combat.

Chapter 2

Literature Review

A concussion is a form of a mild traumatic brain injury (mTBI), which affects approximately 42 million individuals worldwide each year (Musumeci et al., 2019). A concussion is a very common injury but remain largely understudied leaving many gaps in the existing literature. Such gaps lead to a poor understanding of key terminology and concepts related to concussions, which in turn may lead to improper diagnosis and treatment. In recent years, research monitoring breathing function in individuals who have sustained a concussion has increased and an effort has been made to explore the potential effects. This information can lead to better outcomes in the diagnosis and treatment of concussive injuries. Further knowledge on this type of injury can reduce recovery time and improve daily living activities for those suffering from a concussion. Therefore, working towards a greater understanding of the injury and associated negative effects would allow health care providers (HCP) to make informed decisions regarding the care of the patients. Being able to identify what a concussion is, and the consequence of the injury is necessary before this is possible.

Acute Concussion

Mechanism of a Concussion

The brain is one of the most important organs in the human body as it is responsible for an extensive list of functions. All movements, responses, reactions, and processes are connected to and directed by the brain. The brain acts as a command center, leading all organs to perform their functions in cohesion with the rest of the body (Tortora & Nielsen, 2014b). When an injury occurs to the command center, consequences may be observed in multiple systems throughout the entire body. Fortunately, the skeletal structures and systems surrounding the brain are designed to protect and limit damage that may occur (Tortora & Nielsen, 2014a).

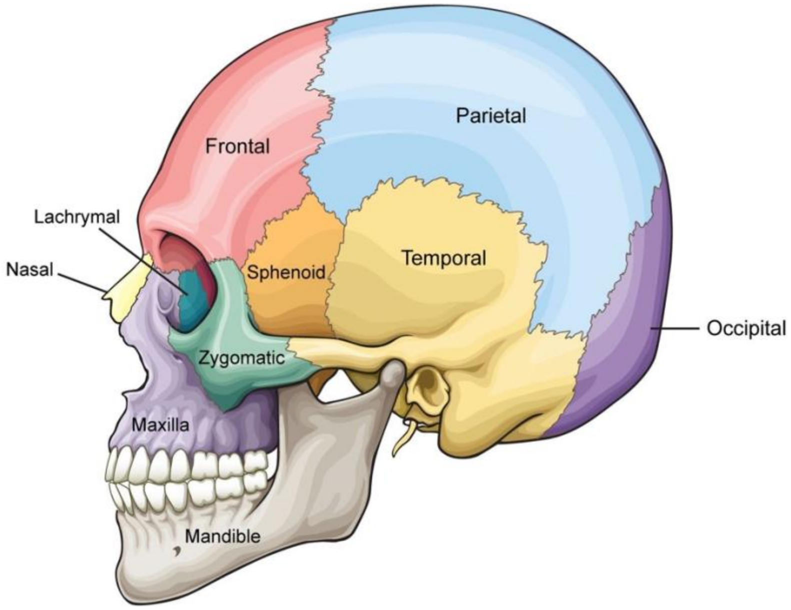


Figure 1. Midsagittal section of the cranial bones. Adapted from *Bones of the skull*. By Aaseng, M., 2019, Maury Aaseng - Medical Illustration & Animation | Duluth.

The skull, the bony structure that encase and protect the brain, consists of eight cranial bones. The cranial bones are named after the section of the brain that they cover including the frontal bone, two parietal bones, the occipital bone, two temporal bones, the sphenoid bone, and the ethmoid bone (refer to Figure 1; Tortora & Nielsen, 2014a). The brain is also surrounded by three layers of cranial meninges that protect the brain. The first layer, the dura mater, is a thick and tough outer layer that is composed of irregular connective tissue. The middle meningeal membrane, the arachnoid mater, is a web-like structure that is filled with interstitial fluid that helps to cushion the brain. The inner-most layer, the pia mater, is a thin layer of connective tissue that houses the vessels that supply O_2 and blood to the brain and spinal cord. These structures act as barriers to deflect forces from directly impacting the neurovascular tissues (refer to Figure 2; Siedlecki et al., 2018; Tortora & Nielsen, 2014b). These protective structures, however, are not always able to withstand the magnitude of the forces inflicted during a concussion.

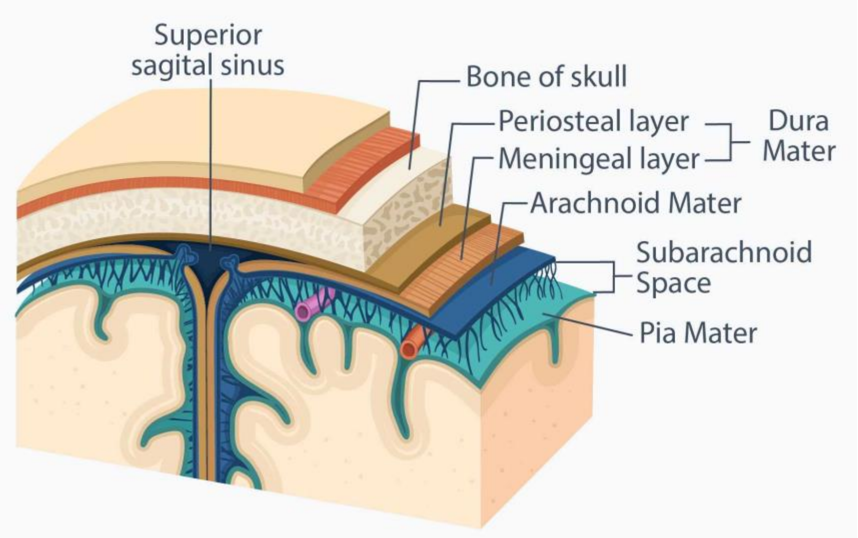


Figure 2. The meningeal layers of the brain. Adapted from *Hydrocephalus symptoms, causes and surgical treatments: MNC*. Symptoms, Causes and Surgical Treatments. from https://miamineurosciencecenter.com/en/conditions/hydrocephalus/

Direct impacts to the head are a well-known cause of a concussion, however, impacts to the body, that result in acceleration, deceleration, and rotational forces, have also been found to produce these types of injuries as well. The brain typically rests in a stationary position and normal movements, or minor bumps and jolts, are mitigated by the falx cerebri and tentorium cerebelli. The falx cerebri and tentorium cerebelli are two structures that act as barriers between the sections of the brain and constrain brain movement (Glaister et al., 2017). Some external forces, however, result in vigorous movement of the brain, pushing it in the opposite direction of the head and producing a collision between the brain and skull (Ferry & DeCastro, 2021). The collision produces functional and microstructural damage to the neural tissues (Giza & Hovda, 2014). Meaney and Smith (2011) concluded that linear and rotational acceleration forces are strongly correlated with the mechanism of injury and occur in virtually all documented concussions. Linear acceleration forces have formed a positive correlation with the pressure inside the brain. When this force is applied, brain pressure increases causing neurological dysfunction, with peak pressure occurring during the period of injury (Meaney & Smith, 2011). Rotational acceleration generates shear forces in the brain causing shear-induced neural and vascular damage. Based on the anatomical structure of the brain, the tissue is more susceptible to shear forces compared to other tissues in the body (Meaney & Smith, 2011). Meaney and Smith (2011) identified that if rotational forces are present in the mechanism of injury, there is a higher likelihood of a LOC. Moreover, the forces associated with concussive injuries have been associated with pathophysiological changes to the brain (Giza & Hovda, 2014).

Neurometabolic Cascade

During the acute stage of a concussion, directly after the injury occurs and, in the days, following, neural axonal shearing and stretching occurs. Shearing and stretching of the brain's connective fibers (axons) occur as the brain rotates and shifts within the skull. As the injury takes place, the release of excitatory neurotransmitters and unchecked ion fluxes occur (refer to Figure 3; Giza & Hovda, 2014). These fluxes lead to changes in cellular physiology. While trying to repair the neuronal membrane potential after a TBI, a malfunction in the sodium potassium pump occurs resulting in a large release of potassium, and an influx of sodium and calcium. The sodium potassium pump requires ATP, energy derived from the breakdown of glucose, that triggers an excessive jump in glucose metabolism leading to hyper-glycolysis and hyper-metabolism of glucose. This process occurs during a time of up to 50% reduction of cerebral blood flow caused by a current injury to the brain. This disparity between the glucose supply and demand causes a cellular energy crisis leading to an energy deficit that can last up to 7-10 days. This energy crisis is a likely mechanism for post-concussive vulnerability, reducing the ability of the brain to respond adequately to a second injury and potentially resulting in the individual experiencing longer lasting symptoms (Giza & Hovda, 2014).

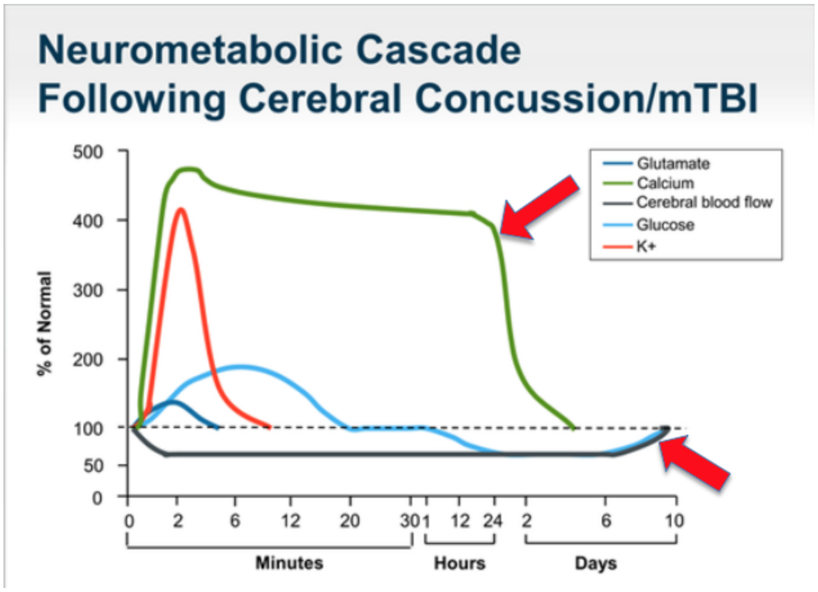


Figure 3. The temporal changes during the neurometabolic cascade. Adapted from Giza, C. C., & Hovda, D. A. (2001). The neurometabolic cascade of concussion. *Journal of Athletic Training*, *36*(3), 228.

Following this period of altered glucose utilization, the brain goes into a period of depressed metabolism which may result in excessive increases in the calcium level and impair the oxidative metabolism worsening the energy crisis (Giza & Hovda, 2001). Calcium accumulation can also activate pathways leading to cell death and disruptions in neurofilaments of microtubules, which could possibly impair post traumatic neural connectivity. Such alterations to the neurotransmission and cellular physiology cause most of the behavioural and cognitive symptoms experienced during a concussive injury (refer to Figure 4; Giza & Hovda, 2014).

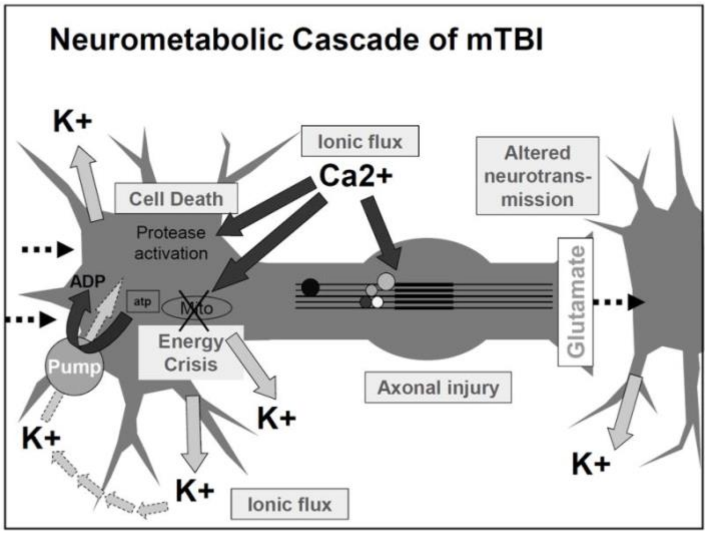


Figure 4. The neurometabolic cascade of mTBI. Adapted from “The New Neurometabolic Cascade of Concussion,” by C. C. Giza and D. A. Hovda, 2014, *Neurosurgery, 75*(4), p. S25.

Giza and Hovda (2001) concluded that following a concussion, cerebral pathophysiology can be negatively affected for several weeks. Their study resulted in significant changes in glucose metabolism in head injured patients that had normal Glasgow Coma Scale (GSC) scores (Giza & Hovda, 2001). This evidence could suggest that guidelines for clinical management of a concussion may need to be improved to better understand and delineate the neurometabolic derangements. Therefore, the physiological changes that occur after a concussion is sustained can result in a significant number of symptoms and subjective complaints which inhibit daily physical and physiological functioning for up to 30 days.

Symptomatology

The clinical presentation of a concussion is highly variable and unique to each individual; therefore, some may present with a variety of symptoms whereas others may not experience any at all (Mccrory et al., 2017). This type of injury is typically diagnosed in a clinical setting by a medical professional using self-report measures to identify and monitor signs and symptoms. A patient with a concussion may immediately present with symptoms such as confusion, disorientation, LOC, or more severe neurological abnormalities (refer to Table 1; Gardner & Yaffe, 2015).

Table 1

Signs and symptoms of a concussion

Somatic	Cognitive	Emotional	Sleep
Headache Fuzzy or blurry vision Dizziness Fatigue Drowsiness Sensitivity to light Sensitivity to noise Balance problems Nausea or vomiting (early on)	Difficulty thinking clearly Feeling slowed down Difficulty concentrating Difficulty remembering new information	Irritability Sadness Feeling more emotional Nervousness or anxiety	Sleeping more than usual Sleeping less than usual Trouble falling asleep

Recently, Ferry and DeCastro (2021) stated that the symptoms of a concussion typically fall withing four main domains. The four domains include physical/somatic (i.e., headache, dizziness, balance, and vision), cognitive (concentration, memory difficulty, and fogginess), mood (irritability or drastic mood changes), and sleep (more or less than usual and drowsiness). If anyone were to experience these symptoms after an impact to the head, neck, and/or body, they should be removed from the environment and referred to a physician to seek proper diagnosis and treatment. It is also important to note that symptoms of a concussion may not occur immediately after a potential injury, it is imperative to observe the individual over the following days (Ferry & DeCastro, 2021). Ferry and DeCastro (2021) stated that the LOC, although an important sign of a potentially serious brain injury, is not typically associated with most concussive injuries. Greater than 90% of concussions present without LOC (Ferry and DeCastro, 2021). The four domains are used to differentiate the subtype of concussion to increase the accuracy of diagnosis, guide management, and classify the severity of the injury (Lumba-Brown et al., 2019).

Similarly, Lumba-Brown et al. (2019) conducted an extensive literature review to characterize the sub-types of a concussion. This study identified five subtypes including cognitive, ocular motor, headache/migraine, vestibular, and anxiety/mood. The subtypes of a concussion are directly related to the structures and functions of the brain that may be affected. This is typically based on where the brain collided with the skull. The domains and subtypes previously listed, are not all symptoms that are typically thought to be associated with concussion. Mann et al. (2017) found significant gaps in knowledge and misconceptions regarding concussion within 348 family medicine residents. This outcome suggests that even individuals who attended medical school in Canada require further education regarding the diagnosis and management of a concussion (Mann et al., 2017). This knowledge constraint may make it difficult for a physician to properly diagnose and treat an individual suffering from this injury.

The cognitive subtype of a concussion refers to the impairment of executive functioning after an injury is sustained. Cognitive impairments that may develop include impaired reaction time, processing speed, working memory, new memory, learning memory, memory retrieval, attention deficits, and decreased organization of thoughts and behaviours (Lumba-Brown et al., 2019). Executive functioning is a fundamental group of skills used in day-to-day living. Executive functioning refers to the brains ability to perform functions such as learning, remembering, reasoning, planning, and problem solving (Blair, 2017; Cristofori et al., 2019). The next subtype, ocular-motor refers to visual dysfunctions. When a concussion is present, it can affect the ability to obtain, understand, and process visual information. These dysfunctions can lead to an extensive list of exacerbating factors such as screen time, reading, driving, and eye fatigue. The headache/migraine subtype is the most common set of symptoms reported after a concussion occurs (Lumba-Brown et al., 2019). Headaches and migraines occur when the blood vessels and muscles that cover the area constrict and expand, resulting in pressure applied to the nerves (Ahmed, 2012). The aggravation is caused by occasional swelling or tightening of the blood vessels or muscles that activates the nerves to send pain impulses to the brain (Ahmed, 2012). The vestibular sub-type is comprised of a combination of vestibular-ocular symptoms such as visual motor sensitivity that causes dizziness, nausea, and vestibular-spinal symptoms that result in gait unsteadiness and poor balance. The final subtype listed is anxiety/mood, which have been known to cause severe mood changes and imbalances such as feelings of depression, feeling overwhelmed, feelings of anger and hostility, and increased fatigue (Lumba-Brown et al., 2019).

These subtypes contain an extensive list of significant symptoms that are known to impair daily living activities and limit the ability to effectively participate in sport, work, or school related activities (Lumba-Brown et al., 2019). There is a potential for serious repercussion with returning to play, school, or work prior to recovery (Williamson & Goodman, 2006). Finally, individuals who previously sustained a concussion or have pre-existing mood disorders, learning disorders, sleep disturbances, or migraines/headaches may have a higher variety, severity, and longer lasting symptoms (Ferry & DeCastro, 2021). Therefore, a comprehensive patient history and evaluation are essential in producing an accurate diagnosis.

Classifications

There have been several attempts at classifying guidelines for the identification and management of a concussion. Currently there are a few predominant documents in circulation, however, there has been significant difficulty in identifying a clear gold-standard among them (Albicini & Mckinlay, 2018). Three of the most cited guidelines and tools include the American Academy of Neurology (AAN) guidelines, the Cantu guidelines, and the Colorado Medical Society guidelines (refer to Table 2). The guidelines for identification and management of a concussion were developed in order to safely indicate if an individual is able to return to a physically or psychologically demanding environment (Albicini & Mckinlay, 2018).

Table 2

Grading Scales for Concussion

Guideline	**Severity of Grade** **1**	 **2**	 **3**
Cantu	(1) No LOC (2) Posttraumatic amnesia lasts less than 30 min	(1) LOC lasts less than 5 min OR (2) Posttraumatic amnesia lasts longer than 30 min	(1) LOC that lasts longer than 5 min OR (2) Posttraumatic amnesia lasts longer than 24h
Colorado	(1) Confusion without amnesia (2) No LOC	(1) Confusion with amnesia (2) No LOC	(1) LOC (or any duration)
Practice Parameter American Academy of Neurology	(1) Transient confusion (2) No LOC (3) Concussion symptom of mental status change resolves in less than 15 min	(1) Transient confusion (2) LOC (3) Concussion symptom of mental status change lasts longer than 15 min	(1) LOC (brief or prolonged)

The severity of a concussion is classified using three categories: grade 1, grade 2, and grade 3. The least severe category is a grade 1 concussion and the AAN have identified three key aspects associated with this grade which include: (1) transient confusion; (2) no LOC; and (3) concussion symptoms or mental status change on examination. The symptoms or changes in mental status observed in a grade 1 concussion often resolve in less than 15 minutes. The AAN suggests a return to activity immediately if symptoms do not last more than 15 minutes. A grade 1 concussion is the most common type of concussion but with such minimal guidelines for identifying the injury it is very difficult to diagnose (Albicini & Mckinlay, 2018). Likewise, a grade 2 concussion, as identified by the AAN, lists an identical set of characteristics as a grade 1 concussion, however, the symptoms are expected to last more than 15 minutes. If a grade 2 injury is suspected with symptoms lasting greater than 15 minutes, individuals are instructed not to return to activity for one week. The most severe concussions are diagnosed as a grade 3 and the only characteristic for this grade is LOC. If the individual is only unconscious for a short period of time, they are suggested to return to activity after one week, but if LOC was prolonged, they are recommended to abstain from activity for two weeks following the injury (Albicini & Mckinlay, 2018).

Similary, to the AAN classification system, the Cantu grading system for concussion is composed of a three-section scale. The Cantu scale characterizes a grade 1 concussion with: (1) no LOC and (2) post-traumatic amnesia lasting less than 30-minutes. Individuals with this grade are suggested to take a week off from activity (Albicini & Mckinlay, 2018; Bailes & Hudson, 2001). A grade 2 injury is characterized by: (1) the LOC that lasts for less than 5-minutes or (2) post-traumatic amnesia lasting longer than 30-minutes. If a grade 2 concussion is suspected, individuals are recommended to avoid activity for two weeks but only if they are asymptomatic for one week. Finally, the Cantu grading scale suggests that the most severe grade, a grade 3 concussion, is characterized by: (1) the LOC that lasts for longer than 5-minutes or (2) post-traumatic amnesia lasting longer than 24 hours (Bailes & Hudson, 2001; Siedlecki et al., 2018).

The final method is the Colorado Medical Society guidelines. This scale seems to suggest a more reasonable and comprehensive return to activity instructions. The Colorado Medical Society guideline has a similar focus on LOC, but this system altered the requirements for each scale as the creators were more aware of potentially catastrophic outcomes such as swelling of the brain or prolonged concussion symptoms (Albicini & Mckinlay, 2018). The Colorado guideline characterizes a grade 1 concussion by: (1) no LOC and (2) amnesia without confusion. If a grade 1 concussion is suspected individuals are to be removed from the activity/environment and immediately assessed for symptoms at rest and during exertional activities. This scale does, however, suggest a return to activity if there is no evidence of symptoms. This is not an ideal recommendation as it has been discovered that it can take up to 24 hours or greater for symptoms to arise in some cases (Albicini & Mckinlay, 2018; Ferry & DeCastro, 2021). Similar to a grade 1, the Colorado guidelines classify a grade 2 concussion with no LOC, but patients may present with amnesia and confusion. As for returning to activity guidelines, it is recommended that individuals are removed from the activity/environment with no immediate return to play. Follow-up assessments are strongly recommended and if the individual experiences a full asymptomatic week, then they are allowed to return to activity. Finally, a grade 3 injury, as identified by the Colorado Medical Society guideline, is the LOC for any period of time. The return to activity instructions are highly detailed for this level of injury, suggesting that immediate transport to a hospital with the cervical spine immobilized is required. After arrival at the medical facility, the individual should be assessed and if neurological symptoms are present, they should be admitted and monitored for neurological findings. If no neurological symptoms are present the individual can go home and return to activity after two weeks of being asymptomatic (Albicini & Mckinlay, 2018).

Most existing grading scales suggest that with the development of a concussion greater than a grade 1, there is likely a period of a LOC; however, 90% of the reported concussions do not result in LOC suggesting that most injuries are grade 1 and possibly less severe (Ferry & DeCastro, 2021). This result may create a grave misconception that a grade 1 concussion is not a serious injury, however, any concussion regardless of the grade is a pressing matter. These scales should be more focused on the number, intensity, and duration of symptoms when attempting to identify the severity of a concussion (Albicini & Mckinlay, 2018). It is no surprise, considering the significant flaws in the grading scales, that many have since been abandoned or retired in exchange for individualized treatment management.

Risk Factors

There are multiple factors that may put an individual at risk of sustaining a concussion. For instance, Harmon et al. (2013) reported that female athletes are at a higher risk of sustaining a concussion with a greater number and severity of symptoms. These athletes experience and document a higher number and severity of symptoms compared to their male counterparts. The cause of this discrepancy between sexes is attributed to the significant difference in the head and neck segment masses. Female athletes tend to have a lower mass percentage resulting in greater acceleration forces being imparted to the brain after the concussive impact has occurred. This discrepancy in head and neck mass percentage reduces the ability to adequately perform protective movements when high forces are applied to the body (Harmon et al., 2013).

Waltzman and Sarmiento (2019) identified another risk factor being age. The researchers discovered that between 2001 and 2012 in the United States, 70% of all mTBI related visits to the emergency room occurred in youth (19 years or younger; Waltzman and Sarmiento, 2019). Due to structural and anatomical differences, youth athletes are found to have a prolonged recovery and a higher chance of sustaining a concussion (Iverson, 2017). Buzzini and Guskiewicz (2006) attributed the structural and anatomical differences to the immature central nervous system (CNS), decreased myelination, greater head-to-body ratio, thinner cranial bones, and reduced neck and shoulder musculature. All the previously mentioned differences contribute to the limited protection and increased vulnerability of the brain to impact forces in this younger cohort.

Finally, individuals who previously sustained a concussion are approximately 2-5.8 times more likely to sustain another concussion (Harmon et al., 2013). Individuals who suffer subsequent concussions are more likely to experience a wider variety of symptoms during baseline testing and meet delayed neurological recovery rates (Lau et al., 2012; Slobounov et al., 2007). Differentiating these differences for at risk groups can be useful in helping HCPs effectively diagnose, treat, and prevent further injury.

Diagnosis

The definition of concussion is a clinical syndrome of biomedically induced alteration of brain function typically affecting memory and orientation, which may involve LOC (Mullally, 2017). A concussion may be subjectively or objectively diagnosed based on the signs, symptoms, or mechanism of injury. The most common mechanism of injury involves powerful acceleration, deceleration, and rotational movements (Mckee & Robinson, 2014). Occasionally, diagnostic tools such as a magnetic resonance imaging (MRI) or computed tomography (CT) may be used to depict the trauma induced on the brain, yet they do not always identify the injury effectively (Broglio et al., 2017). Therefore, the diagnosis heavily relies on how the injury occurred and the symptoms the individual is experiencing (Mullally, 2017). Over the years, there have been increased effort in the development of detailed screening tools for the identification, diagnosis, and management of a concussion. More specifically, these diagnostic tools have been developed to classify concussion symptoms and identify if an individual self-reports or presents with cognitive abnormalities (Mann et al., 2017). Furthermore, there have also been scales developed to monitor the severity and consequences post injury. The tools used post injury can give values and insight into the rate of recovery and return to work, play, and/or school readiness (Quatman-Yates et al., 2020). A few of these tools include the GCS, the Sport Concussion Assessment Tool 5th edition (SCAT 5), and the ImPACT®.

The Glasgow Coma Scale. This scale is one of the most cited tools that is used to objectively assess the level of impaired consciousness (Gardner & Yaffe, 2015; Jain & Iverson, 2021). This scale assesses eye, verbal, and motor responses in all individuals over the age of 5 years with no necessary modifications. Those who typically suffer from a concussion will score anywhere between 13-15 (on a 15-point scale). The GCS has been used since the 1980s and has been frequently administered to trauma patients. Although it cannot be used to diagnose a concussion, this scale gives a useful summary of the overall severity and rules out more serious TBIs. This scale is also useful in monitoring individuals and guiding changes in the management of a TBI (Jain & Iverson, 2021). The overall reliability of the GSC was deemed moderate (.66-.77; Reith et al., 2017) whereas the inter-rater reliability was high for each respective section (eye=89%, motor=94%, and verbal= 88%; Gill et al., 2004).

Sport Concussion Assessment Tool 5th edition. The SCAT 5 is a highly comprehensives diagnostic tool that was created for qualified health care professionals to evaluate sport related concussion (SRC) in individuals 13 years or older. The SCAT 5 also has a child SCAT 5 version that can be used on children aged 5-12 years as well as a Concussion Recognition Tool (CRT) that can be used by non-medically trained individuals (Echemendia, 2017). The CRT was designed to aid in the initial management of a suspected concussion when a medical professional is not present (Echemendia, 2017). If performed correctly, the SCAT 5 should take a minimum of 10 minutes to complete. The SCAT 5 is comprised of an immediate on-field assessment and off-field/office assessment.

The immediate on-field assessment is broken down into 5 sections including: (1) red flags, (2) observable signs, (3) memory assessment Maddocks questions, (4) GCS, and (5) cervical spine assessment. The first section, red flags, consists of immediate signs after a head injury occurs. Red flags may be reported by the injured individual including symptoms such as neck pain, double vision, or severe or increasing headache. Red flags may also be reported by a witness, for example, the observation of seizures/convulsions, LOC, and restless or combative behaviours by the individual suspected of having a concussion. The observable signs section refers to behaviours detected by a witness including disorientation or confusion, the presence of a blank or vacant look, facial injury after trauma, and lying motionless on a playing surface. The third section of the assessment includes the Maddocks questions assessing memory. The injured individual is asked questions to identify their awareness for current and recent events. Some of the questions in this section inquire about location/venue, which half, or quarter of the game it was, and what the score was. The fourth section, the GCS, is used to assess the level of impaired consciousness by observing eye, verbal, and motor responses as described in detail previously. The final section, the cervical spine assessment, is used to record neck pain and assess cervical spine active range of motion and limb strength (Sport Concussion Assessment Tool, 2017).

The second component for the office or off-field assessment consists of the completion of the: (1) athlete background, (2) symptom evaluation, (3) cognitive screening, (4) neurological screening, (5) delayed recall, and (6) the decision (Sport Concussion Assessment Tool, 2017). The athlete background obtains demographic information (i.e., age, education, and sport participation) and information related to the patient's past medical history (i.e., prior mTBIs and learning disorders). The symptom evaluation component is a subjective questionnaire that asks the patient to rate the symptoms they have at that point in time. The next component, cognitive screening, assesses the individual's current orientation, asking questions about the current month, date, year, and approximate time. The following component of cognitive screening evaluates the immediate memory (i.e., recalling key words) and concentration (i.e., repeating back a set of numbers). Next is the neurological screen, and this section assesses components such as verbal skills, cervical spine, coordination, and balance. The fifth section, delayed recall, tasks the participants with recalling words from the immediate memory section. The final component, the decision, compiles the information received from the in-office assessment to identify if a concussion is suspected (Sport Concussion Assessment Tool, 2017). The main disadvantage to the SCAT 5 is the qualifications required to be utilized, as not all sport teams are able to have a medical professional (e.g., physician) in attendance at each game or practice (Echemendia, 2017). This is especially true for teams with younger athletes or amateur sports teams with a lower budget; however, the SCAT 5 provides the CRT that gives non-medical individuals the information required to determine if a trip to the emergency room is required. The SCAT 5 is an screening tool, however, unlike the GCS, the SCAT 5 was identified to have limited validity in tracking recovery and advising return to play. This version of the SCAT has significantly contributed to the development of acute evaluation of concussive injuries by addressing limitations identified by its predecessors (Sport Concussion Assessment Tool, 2017). With a high test-retest reliability (.85) this test strives to stay up to date on current concussion research, utilizing all of the available literature to provide the most thorough diagnostic measures (Echemendia, 2017; Hänninen et al., 2021).

ImPACT®. The ImPACT® battery is a commonly used computerized neurocognitive test designed specifically as a measure of executive function in healthy and concussed populations (Schatz et al., 2006). The test measures different dimensions of executive function including visual and verbal memory, working memory, processing speed, visual-motor skills, and reaction time. The computerized test consists of the participant completing a demographic profile, completing the Post-Concussion Syndrome Scale questionnaire (PCSS), and six test modules. The ImPACT® battery requires approximately 25-30 minutes to complete on a computer (Lovell, 2015). When possible, individuals complete this assessment as a baseline measure, therefore, when a potential concussion is present, the ImPACT® test can be completed to address any potential discrepancies and give a firmer diagnosis (Lovell, 2015). Overall, a concussion can be challenging to diagnose due to the hidden nature of the injury and variety of symptoms for each individual, however, the tools that have been developed in order to make the process easier have been an addition to the assessment process and concussion research (Albicini & Mckinlay, 2018). The ImPACT® test was utilized for this study and is discussed further in the methodology section.

Treatments

A concussion is a unique injury as it can cause a variety of symptoms and temporary impairments in daily living (Ferry & DeCastro, 2021). The neurological deficits and symptoms for a first concussion in adults usually resolve with full recovery in 7-15 days (Ellis et al., 2016; Tator, 2013). Treating a concussion typically incorporates a brief period of physical and cognitive rest, followed by a gradual increase in activity, along with consistent check-ins until medically cleared (May et al., 2020; Schneider, 2017). Following the initial injury, the individual should be monitored and treated for consequences such as depression and anxiety. Initially reducing physical and physiological activity provides the opportunity to repair the metabolic impairments (May et al., 2020). If an individual continues to participate in physical and cognitive activities directly after an injury is sustained, an increased number and severity of symptoms may occur (Tator, 2013). Continued participation also puts the individual at risk of sustaining a second injury that could result in SIS and have fatal consequences (Williamson & Goodman, 2006). Using the diagnostic guidelines and identifying the symptom and subcategories an injury falls under leads to the development of a treatment plan tailored to the needs of each individual at that given stage (Quatman-Yates et al., 2020). Some individuals may require specialized treatment if there is significant damage that results in cognitive, auditory, and ocular motor impairments that may also need to be considered (Quatman-Yates et al., 2020).

Concussion in the Military

A concussion is the most common type of TBI, yet somehow diagnostic tools, classification scales, and treatment processes remain elusive (Edwards et al., 2020). Most concussions occur due to a direct or indirect impact to the head, face, neck, or body (Mckee & Robinson, 2014). Therefore, when discussing a population that is often exposed to potentially life-threatening circumstances, it is important to take into consideration how injuries such as a concussion will affect them. Acceleration, deceleration, rotational, and blast injuries are often seen in military personnel throughout daily training and when exposed to harmful environments like a war zone (Mullally, 2017). The increase in use of improvised explosive devices has also been shown to increase the risk of TBI as it affects multiple organs and systems in the body, including the CNS. Research shows that military personnel are exposed to almost the equivalent risk of a concussion as National Collegiate Athletic Association (NCAA) athletes in the United States (Broglio et al., 2017). Zuckerman et al. (2015) conducted a study to collect updated data on the epidemiology and occurrence of concussions in NCAA athletes between 2009 and 2014. Across 25 NCAA sports, approximately 10,560 sport related concussions were reported. Zuckerman et al. (2015) suggested that the military populations who are exposed to dangerous, potentially lethal, and physically demanding scenarios may be at an even greater risk for developing these types of injuries (Holtkamp et al., 2016).

The equipment provided for military service members has improved immensely over the years, significantly reducing the mortality rate compared to previous combat (Xydakis et al., 2008). However, with the modernization of weapons and technologies, the ability to harm and disable individuals is becoming increasingly threatening. For example, the recent updates in blast frequency have made concussion and severe TBIs more common among war zone troops than ever (Gardner & Yaffe, 2015). It is important to keep in mind that in training or when overseas these individuals are often exposed to repetitive sub concussive/concussive injuries. Military members may be required to shoot a high number of rounds on large caliber weapons, skydive with heavy equipment, set off explosive devices from short distances, and engage in hand-to-hand combat. Each of the examples provided can lead to repetitive sub concussive/concussive injuries that may exacerbate and/or produce a variety or symptoms that inhibit daily physical and physiological functioning. These types of repetitive injuries have also been linked to neurodegenerative diseases like CTE, Alzheimer's, and dementia (Mckee & Robinson, 2014).

With the number of concussive injuries increasing, there are growing concerns regarding the long-term effects. Mullally (2017) explained that in multiple post-mortem examinations of military veterans, there were findings that showed repeated brain injuries that led to permanent neurological abnormalities consistent with diseases such as Alzheimer's disease and dementia (Bieniek et al., 2015; Musumeci et al., 2019). Xydakis et al. (2008) stated that many troops reported post concussive symptoms that alter emotional and cognitive functioning, thus, screening measures for military members and veterans have since been implemented. Xydakis et al. (2008) also reported that the majority of mTBI research has been conducted on civilian patients in hospitals or clinics. Hence the importance of expanding research and HCPs area of knowledge on this topic due to the risk of the health and safety of military members. Since 2000, on average 22,800 out of the approximately 1 million active service members reported a concussion annually in the United States military (Oberman et al., 2020). This is a relatively common injury, keeping in mind that concussive injuries are frequently underreported (Joyce et al., 2015). Due to the high prevalence of concussive injuries in the military and the physiological processes that may be affected by this injury, it is crucial to also understand the possible effects on the physiology of breathing.

Breathing Physiology

General Overview

The process of breathing relies on the responsibilities and functions of the upper (i.e., nose, larynx, and pharynx) and lower respiratory tracts (i.e., trachea, brachial tree, and lungs) to permit the movement, collection, and expulsion of gases (Tortora & Nielsen, 2014c). Via inhalation, air travels into the upper tract through the trachea and is pulled into the lungs where it reaches the alveoli and pulmonary capillaries where the filtered exchange between O_2 and CO_2 takes place. This produces a balance between the O_2 and CO_2. The waste gas, CO_2, the by-product of cellular respiration (whereby glucose and O_2 are used to form ATP) is removed through expiration (refer to Figure 5; Patel et al., 2021). The human body requires O_2 to survive and after it is absorbed through the processes in the lungs, it is transported to the cells, organs, and tissues via the blood stream (Sarkar et al., 2017). If the human body is deprived of O_2, hypoxia will result and after several minutes death may occur to the brain and the entire body as organs begin to fail (Sarkar et al., 2017). Since O_2 is required for energy production, as the physical demand increases, so does the demand for O_2 (Kenney et al., 2012). For example, when put under physical stress (i.e., walking or running) the body will receive signals from the brain to increase the rate of breathing (Kenney et al., 2012).

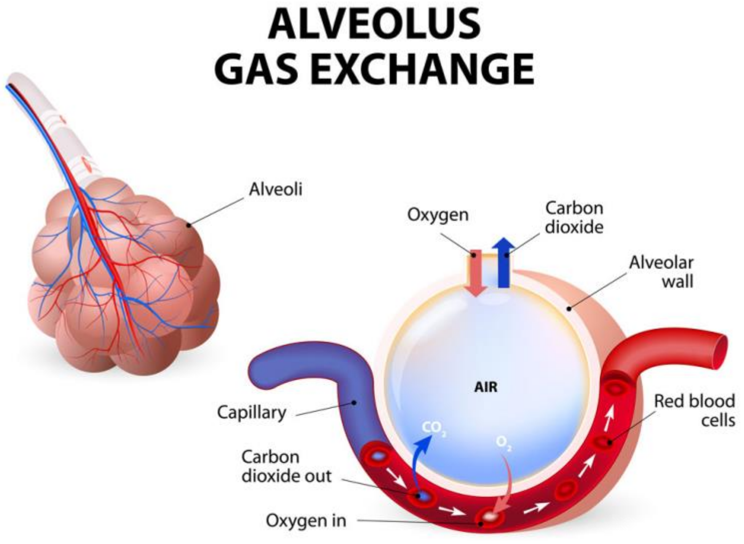


Figure 5. Gas exchange of O_2 and CO_2 between an alveolus and pulmonary capillary red blood cell. Adapted from Schochet, P. N., MD. (2015, December 07). Alveolus-gas-exchange-Pulmonary-alveolus. Retrieved from https://www.pedilung.com/pediatric-lung-diseases-disorders/anatomy-of-a-childs-lung/alveolus-gas-exchange-pulmonary-alveolus/

Another large contributor to the mechanics of breathing is a vast collection of muscles within the chest wall. The first step of inhalation is the expansion of alveoli in the lungs, followed by the contraction of the diaphragm (Tortora & Nielsen, 2014c). This contraction causes the diaphragm to flatten, increasing the diameter of the thoracic cavity. The diaphragm accounts for approximately 75% of the air that enters the lungs during normal breathing. While the diaphragm is contracting the external intercostal muscles become active pulling the ribs superiorly and pushing the sternum anteriorly. The intercostal muscles keep the intercostal spaces from collapsing inward as it would reduce the thoracic volume and increase pressure. As the diaphragm and external intercostal muscles contract, the size of the thoracic cavity increases, and the walls of the lungs expand (Tortora & Nielsen, 2014c). As the volume of the lungs increase, the alveolar pressure is decreased. A pressure gradient is established between the atmosphere and the alveoli. The pressure gradient results in atmospheric air being pulled into the lungs where inhalation takes place. During forceful inhalation, there are accessory muscles that minimally contribute, including the sternocleidomastoid muscles (elevates the sternum), the scalene muscles (elevates the first two ribs), and the pectoralis minor muscles (elevates the third through fifth ribs; Tortora & Nielsen, 2014c).

Exhalation begins with the relaxation of the inhalation muscles. During this time, the external intercostal muscles become less active, and the ribs move inferiorly (Tortora & Nielsen, 2014c). The diaphragm moves superiorly reaching its end-range elasticity. The decreased space in the thoracic cavity results in surface tension and an inward pull of the lungs resulting in a decreased volume. The pressure in the lungs increases, pushing the air into a location of lower pressure, the atmosphere. During labored breathing, the muscles of exhalation including the abdominal and internal intercostal muscles contract. The contraction moves the ribs inferiorly leading to compression of the abdominal viscera, forcing the diaphragm superiorly (Tortora & Nielsen, 2014c).

Two more key structures related to respiratory control include the medulla oblongata and pons (refer to Figure 6; Tortora & Nielsen, 2014b). Both structures exist inside the brainstem which is located between the spinal cord and the diencephalon. The pontine respiratory group, located in the pons, works in conjunction with the medullary respiratory group, located within the medulla oblongata, to control breathing. The pons sits above the medulla and in front of the cerebellum within the brainstem (Tortora & Nielsen, 2014b). The pontine respiratory group consists of a group of neurons that activate during inhalation and inhalation, sending impulses to the medullary respiratory group (Tortora & Nielsen, 2014c). While active during inhalation and exhalation, this group of neurons can also make modifications in basic breathing rhythm during certain activities (i.e., exercising or speaking; Tortora & Nielsen, 2014c). The medulla oblongata is positioned at the base of the brain and connects the brain and spinal cord (Ikeda et al., 2017). The medulla oblongata is responsible for the passing of messages between the brain and spinal cord. This structure also controls the autonomic nervous system (ANS) that regulates the cardiovascular and respiratory systems (Tortora & Nielsen, 2014b).

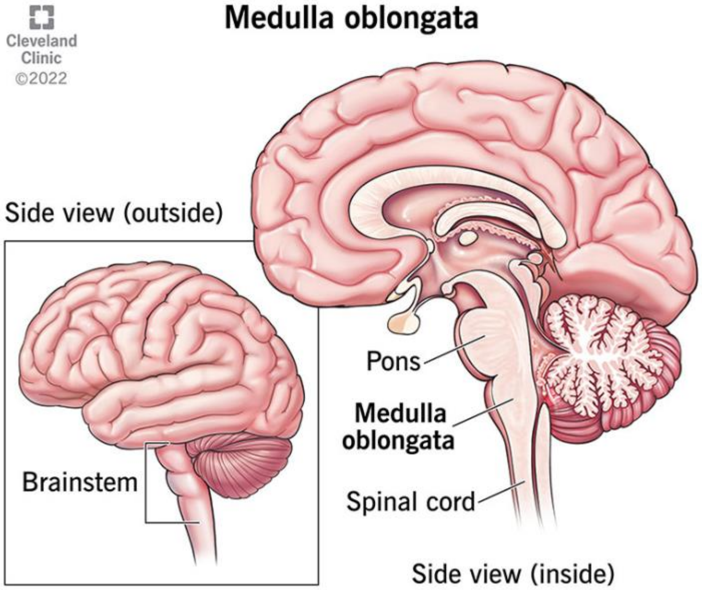


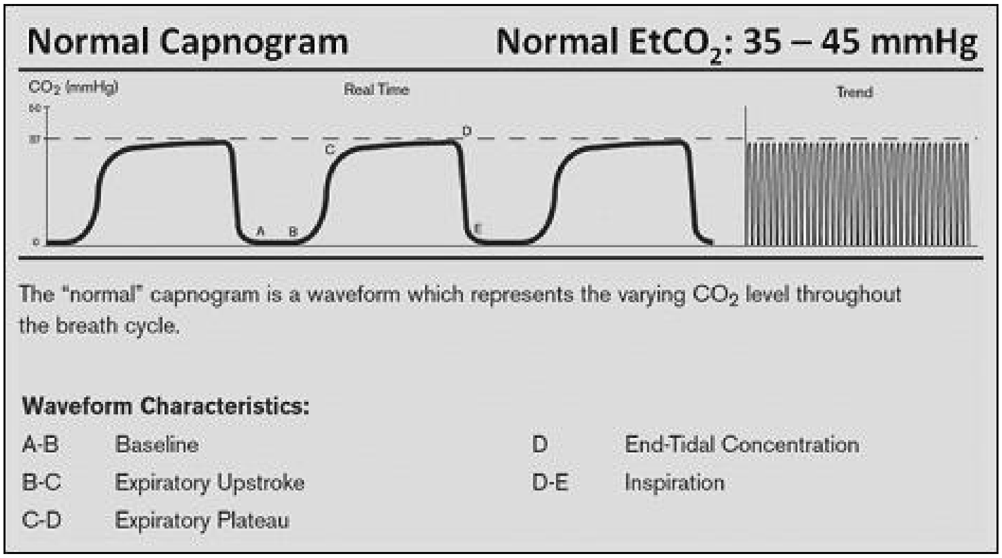
Figure 6. The brainstem, medulla oblongata and the pons. Adapted from *Medulla oblongata: What it is, Function & Anatomy*. Cleveland Clinic. (2022) from https://my.clevelandclinic.org/health/body/23001-medulla-oblongata#anatomy

The medulla oblongata maintains respiratory regulation by sending signals to the body on a continuous basis (Ikeda et al., 2017). The ANS is responsible for signaling the upper and lower respiratory tract, that moves O_2 into the body and expels waste gases such as CO_2 (Patwa & Shah, 2015). While the ANS is mainly responsible for gaseous exchange and controlling the RR, humans can also voluntarily override this process to allow for functions such as modifying one's breathing and vocalizations (Maclarnon & Hewitt, 1999). During physical activity and exercise, the sympathetic nervous system (SNS), a division of the ANS, is stimulated and signals the adrenal medullae to release the hormones epinephrine and norepinephrine. Both hormones result in the relaxation of the smooth muscle of the bronchioles, which dilate the airways. This increases lung ventilation because the air reaches the alveoli more rapidly (Tortora & Nielsen, 2014c). Based on the importance of the respiratory system, it is useful to understand the process of how breathing function is investigated.

Measuring Carbon Dioxide

Partial pressure of CO_2 is a representative measure for the balance of CO_2 production and elimination in the human body. The $PPCO_2$ measures provide important information regarding metabolism, pulmonary function, breathing patterns, and behaviours (McLaughlin, 2014). The gold standard measure of $PPCO_2$ is obtained through arterial blood gases, requiring an invasive blood sample taken through a radial artery puncture (McLaughlin, 2014). This test is usually completed in a laboratory or hospital setting by a health care professional of which it is in within their legal scope of practice to perform these duties. The arterial blood sample, however, only provides measures of CO_2 values based on the time when it was drawn from the individual. Since CO_2 values change on a breath-by-breath basis, this invasive and time-consuming test ultimately limits detections of poor breathing behaviours (McLaughlin, 2014). A capnography unit, however, captures continuous data with each breath. This portable device has become increasingly popular and is expected to be the new gold standard (McLaughlin, 2014).

The CapnoTrainer® is a portable capnography breath analyzer that was utilized in the study to measure CO_2 at the end of exhalation ($ETCO_2$) and the number of breaths per minute (RR; refer to Figure 7 McLaughlin et al., 2011). The $PPCO_2$ and $ETCO_2$ levels strongly correlate and are interchangeable, therefore, making measures of this sort more accessible to a wider population and less invasive (Richardson, 2016). Capnography measurements (RR and $ETCO_2$) indicate the effectiveness of the blood to carry CO_2 back to the lungs and exhale it. The capnography unit records expelled $ETCO_2$, and information related to the RR in a comprehensive capnogram waveform that is recorded on a laptop computer running the CapnoLearning 4.0 PhysioLab software. The CapnoTrainer® provides a value of CO_2 at the end of an exhaled breath.



The "normal" capnogram is a waveform which represents the varying CO_2 level throughout the breath cycle.

Waveform Characteristics:

A-B	Baseline	D	End-Tidal Concentration
B-C	Expiratory Upstroke	D-E	Inspiration
C-D	Expiratory Plateau		

Figure 7. Capnogram Waveform. *Zoll Medical Corporation*. Medical Devices and Technology Solutions - ZOLL Medical. (n.d.). Retrieved January 31, 2022, from https://www.zoll.com/medical-products/defibrillators/r-series/capnogram

Physical Tasks

Although there have been some variations over time the most recently updated resting range of RR typically is between 12-20 breaths per minute (Hill & Annesley, 2020). During physical activity, RR values are expected to climb due to increased energy expenditure and increased O_2 demands. The increased RR occurs as the body burns through the existing energy stores located within the muscles and the increased uptake provides the muscles the O_2 required to convert available glucose into ATP (Kenney, et al., 2012).

The normal resting measures for $ETCO_2$ are generally between 35-45 mmHg (Braun,1990; Mclaughlin, 2014). As previously stated, the $PPCO_2$ is the current gold standard for obtaining these measures via arterial blood gases, requiring an invasive blood sample through a radial artery puncture, and only providing measures of the CO_2 levels at the time they were drawn (Mclaughlin, 2014). Therefore, using a capnography unit during physical activity would provide more comprehensive and continuous measures for the entirety of the task. The portable unit provides convenient and non-invasive measures that it is often preferred over the $PPCO_2$ measure (McLaughlin, 2014). End-tidal CO_2 measures normally increase during exercise and is not abnormal for these values to reach above 40 mmHg (Hoshimoto-Iwamoto et al., 2009). Hoshimoto-Iwamoto et al. (2009) investigated $ETCO_2$ values in individuals with left ventricular dysfunction. The researchers concluded that abnormally low $ETCO_2$ levels at peak exercise were found to be predictors of cardiac death, providing a poorer prognosis for individuals with left ventricular dysfunctions (Hoshimoto-Iwamoto et al., 2009). This team of researcher's stated that within this population the gaseous exchange that is supposed to occur in the lungs was not as effective as in a healthy individual, resulting in a lower PPO_2 and increased pressure of CO_2. Decreased O_2 pressure combined with increased CO_2 pressure is a sign of poor pulmonary function, suggesting that the lungs are unable to effectively inspire sufficient O_2 and expire the CO_2 by-product (Hoshimoto-Iwamoto et al., 2009). Similarly, breathing changes have also been linked to cognitive load and stress (Grassmann et al., 2016). This will be discussed further in the following section.

Cognitive Tasks

Cognitive functioning is responsible for many components of daily living activities. A measure of executive functioning can provide insight and address any discrepancies in areas such as processing speed, immediate memory, and working memory. When people are highly focused, aspects of their breathing will change to accommodate for the cognitive processes that are occurring. Grassmann et al. (2016) evaluated the respiratory changes in response to cognitive loading and reported that breathing behaviors typically reflected the cognitive loads applied. The researcher suggested that as the cognitive process becomes increasingly difficult, stress is applied to the respiratory system leading to decreased $PPCO_2$ and increased RR and minute ventilation (MV; Grassmann et al., 2016). Grassmann et al. (2016) defined MV, not to be confused with RR (breaths per minute), as the amount of air that is inspired within one minute.

Similarly, Yadav and Mutha (2016) conducted a study examining deep breathing practice and retention of new motor skills. The researchers discovered significant improvements of skill retention after 24 hours observed in individuals that incorporated the deep breathing practices. This research further shows the interconnectedness between executive functioning and effective breathing. Based on the knowledge of how breathing behaviours and cognitive functioning are interrelated, research further examining breathing patterns in individuals who have sustained a mTBI may help build a better understanding of how dysfunctional breathing affects daily living activities in this group (Siedlecki et al., 2018).

Concussion and Breathing

The physiology and mechanics of breathing is achieved through the impressive collaboration of many structures. Understanding the number of structures and functions involved in performing the act of breathing leads to the question of how breathing is regulated or how the human body knows when O_2 is indicated, and CO_2 needs to be expelled. It can be assumed then that breathing, and brain function, have a symbiotic and complex relationship, like the rest of our body's structures and functions. As previously mentioned, the medulla oblongata and pons host two important respiratory structures. The pontine respiratory group and the medullary respiratory group that collaborate to control breathing. The medulla also controls the ANS, responsible for regulating the cardiovascular and respiratory systems (Ikeda et al., 2017). Oxygen is the most important thing that humans consume daily, whereas CO_2 is the waste gas that we produce and exhale and becomes toxic if not released (Patwa & Shah, 2015). Therefore, the medulla oblongata maintains respiratory regulation by signaling the body on a continuous basis (Patwa & Shah, 2015).

A concussion can impact any individual and seriously affect daily brain function depending on the location of the injury. During a concussion damage can occur to several structures in the brain resulting in neural and vascular tissue shearing. These shearing forces can cause physiological changes in the brain. If structures such as the medulla oblongata, pons, or middle cerebral artery are damaged, blood flow to the respiratory control centres may be restricted and function impacted (Ikeda et al., 2017). These blood flow restrictions could result in highly abnormal and dysfunctional breathing patterns causing respiratory distress. These may greatly affect the ability of the individual to perform physical activity related to daily function, sport participation, and effectively engage in a physically demanding career and complete work tasks. Factors that have been shown to alter breathing patterns include increased feelings of anxiety and the presence of anxiety disorders, heart failure, and mTBIs (Whited & Graham, 2021).

A study conducted by Siedlecki et al. (2018) examined $ETCO_2$ and RR during a physical and a neurocognitive task in civilian individuals with PPCS compared to healthy civilian individuals. Siedlecki et al. (2018) used the CapnoTrainer® to measure $ETCO_2$ and RR while completing a walking task on a treadmill and a neurocognitive task using the ImPACT®. This study identified significant differences between $ETCO_2$ in individuals with PPCS compared to healthy individuals. The researchers suggested that individuals experiencing concussion symptoms for an extended period of time may have developed altered breathing patterns at rest. It was proposed that the altered breathing patterns may have occurred due to the trauma sustained during a concussion.

Similarly, Snyder et al. (2021) conducted a pilot study that examined cardiorespiratory functioning in youth with PPCS. This study was conducted using standardized self-report questionnaires for a neurobehavioral assessment and the Capnostream™. Snyder et al. (2021) used the Capnostream™ to measure $ETCO_2$ levels, RR, HR, and SaO_2 in an attempt to identify if cardiorespiratory dysfunctions were present while breathing normally in a seated position. They reported significantly lower $ETCO_2$ measures in participants with PPCS compared to controls as well as increased variability in HR in individuals with PPCS. More specifically, the individuals who were experiencing PPCS had an increased difficulty either circulating the CO_2 back to the lungs or expelling the CO_2 out of the lungs. Heart rate variability (HRV) is the variation of the period of time between heartbeats. The variability in HR can provide important information regarding physiological factors that modulate the normal rhythms of the heart (Rajendra et al., 2006). Heart rate variability can lead to predictors in health issues related to the ANS, SNS, and cardiovascular system. This study suggested that individuals who suffered from a concussion and were experiencing PPCS had a more difficult time processing and removing CO_2 in their exhaled breath than their non-concussed counterparts. Both Siedlecki et al. (2018) and Snyder et al. (2021) concluded that more research is required to further evaluate breathing patterns in individuals with PPCS.

Many studies have shown that breathing dysfunctions such as agonal breathing (i.e., slow, shallow, and irregular breaths) have been linked to certain types of brain injuries (Whited & Graham, 2021). The existing literature that has identified the risk and prevalence of concussion within the military, however, lacks the component of investigating potential breathing abnormalities within the concussed population. To the student researcher's knowledge, this was the first study that examined if breathing function is affected by concussive injuries in military members. Therefore, further research is warranted, due to the prevalence of brain injuries that occur during training and combat.

Purpose of Research

A concussion can affect many different structures in the brain, if certain structures like the medulla oblongata or pons are injured then respiratory abnormalities or dysfunctions may occur. Breathing abnormalities and dysfunctions can lead to poor gaseous exchange causing abnormal levels of O_2 and CO_2 in the blood and lungs (Patwa & Shah, 2015). As previously mentioned, the gas exchange leading to O_2, and CO_2 balance is one of the most important functions that the human body performs. Every structure and organ in the human body requires O_2 to survive and effectively perform their responsibilities (Patwa & Shah, 2015). Therefore, if respiratory abnormalities and/or dysfunctions are present in military members who have had a concussion within the past 2-12 months, the ability to perform daily living activities and advanced career related activities (i.e., physical activity, executive functioning tasks) may be altered. More specifically, executive functioning and/or physical deficits could lead to mistakes or the inability to physically perform, make decisions, and/or problem solve in a life-threatening situation. If breathing abnormalities exist in concussed military members, it is important that it be addressed from a diagnostic and treatment perspective. Therefore, the purpose of this study was to examine differences between healthy and concussed military members on measures of $ETCO_2$ and RR when completing a neurocognitive task (ImPACT®) and a physical task (walking on a treadmill with a weighted vest). This study also aimed to examine differences between healthy and concussed military members on executive functioning scores when completing a neurocognitive task (ImPACT®).

Guiding Questions

The following three questions were developed to guide this study:

1. What were the effects of a physical task (walking while wearing a weighted vest) compared to a neurocognitive task (ImPACT®) on $ETCO_2$ in healthy versus concussed military members?
2. What were the effects of a physical task (walking while wearing a weighted vest) compared to a neurocognitive task (ImPACT®) on RR in healthy versus concussed military members?
3. Was there a difference in executive functioning scores during the completion of the ImPACT® neurocognitive test between healthy versus concussed military members?

Chapter 3

Methodology

Participants

The study recruited 30 male and female participants, between 18-59 years of age who were divided into two groups: healthy military members (n=17) and concussed military members (n=13). The number of participants was derived by a priori power analysis. The sample size calculation included a large effect size value of .44, 80% power of rejection, and an alpha level set at .05.

Recruitment

Prior to recruitment, the student researcher applied to the Lakehead University Research Ethics Board (REB). Once the REB application was approved, recruitment for the study began. Seventeen healthy and 13 concussed military members were recruited for this study through convenience sampling. An electronic version of the recruitment poster and recruitment information letter (refer to Appendix A and Appendix B) were emailed to the physical therapy (PT) department of the Canadian Special Operation Forces Command (CANSOFCOM). The poster outlined a brief description of the study, the inclusion criteria, and the student researcher's contact information. Similarly, the recruitment information letter included the purpose of the study, who was being recruited, and the primary researchers' contact information. If an HCP/gatekeeper had identified an individual as meeting the criteria for the study, the gatekeeper asked the individual if he/she was interested in participating. If the individual was interested, the HCP provided them with the primary researchers' contact information. Additionally, if consent was obtained, the physical therapy department provided the student researcher with the contact information of the interested individuals. Once contact was made with the participant, the student researcher booked the individual into the data collection schedule. This study took place at the Heritage Fitness Centre in Carleton Place, ON.

Inclusion Criteria

Participants for both groups (healthy and concussed) included males and females between the ages of 18-59 years who were active military members. This age range was to limit variability and ensure all participants were not in any major developmental or neurodegenerative phases. Lung function progressively decreases, after the age of 25 years, however, the physiological changes were only found to affect drug prescription (i.e., asthma inhalers). The functional change in the airway receptors alters the response to treatments typically used for younger individuals (Sharma & Goodwin, 2006). Significant age-related changes in breathing physiology begins at approximately 80 years of age, while significant age-related cognitive decline is expected to occur between 60-70 years of age (Salthouse, 2009). Therefore, to avoid significant physiological or cognitive decline that could have skewed the results of the study, the upper age limit was set at 55 years. The compulsory age of retirement in the CAF is 60 years of age, however, the retirement age may vary for some individuals (Department of National Defence. 2017).

All participants were required to understand verbal and written instructions in English and were able to provide consent. The healthy military members were required to have not sustained a concussion within the last 24 months prior to data collection. The concussed military members were required to have been diagnosed with at least 1 concussion by a medical professional within the past 2-12 months. Based on previous literature surrounding concussive injuries it has been identified that symptoms in most adults resolve within 7-15 days, however, some individuals may have deficits for several weeks lasting up to one year or more (Ellis et al., 2016; Permenter et al., 2022). Military members who were mildly symptomatic were still included for this study, but ultimately, had to be cleared by a medical professional to return to work.

Exclusion Criteria

Participants were excluded from this study if he/she had any debilitating injury or condition which would have prevented them from safely engaging in physical activity (e.g., lower limb fracture, muscle strain, or ligament sprain) or any other neurological disorder (e.g., stroke, amyotrophic lateral sclerosis, or Alzheimer's disease) that may have altered their results and/or performance. Although a concussion is classified as a neurological disorder, the participant must not have had any neurological disorders other than a concussion (i.e., cerebral palsy or Down's syndrom). Participants were also excluded from this study if he/she had any previous existing respiratory dysfunctions (e.g., asthma and bronchitis). The Nijmegen Questionnaire (NQ) score ranges from 0-64, with a score of 19 or above suggesting a potential breathing disorder or the presence of respiratory distress. Therefore, if a participant scored below 19, they were included in the study but if they scored a 19 or above, they were no longer permitted to participate. Additionally, if an individual had scored above a 19 on the NQ with no prior diagnosis of a breathing disorder the student researcher would have recommend that they speak with a medical professional for additional testing. None of the participants in this study produced NQ scores of 19 or greater, therefore, all were welcome to participate.

Screening Measures and Instruments

Several screening measures and instruments were used in this study. Prior to data collection participants were provided with an information letter (refer to Appendix C), a consent form (refer to Appendix D), and a demographic interview that was conducted by the student researcher. General information about the participant was recorded during the process, including the participant's date of birth, height, body mass, length of military service, and history of previous concussions. Throughout the data collection process, the NQ, ImPACT®, CapnoTrainer®, and a weighted military vest were also used.

Nijmegen Questionnaire

The NQ (refer to Appendix E) was administered and utilized as a screening tool to identify the breathing patterns of the participant. The 16-item self-report questionnaire gave the individuals the opportunity to score any dysfunctional breathing symptoms they may have been experiencing. This questionnaire was structured to identify the physiological and psychological processes that relate to breathing disorders. The NQ covers a magnitude of bodily systems that have been known to alter breathing patterns including the gastrointestinal, neurological, and cardiovascular systems (Dixhoorn & Folgering, 2015). Some examples found in the NQ include questions regarding shortness of breath, tightness across the chest, and difficulty breathing or taking deep breaths. Each item was ranked on a 5-point Likert scale ranging from 0 (never) to 4 (very often). The maximum total score for the NQ is 64 and the higher the individual's total score, the higher the likelihood that individual may have had a breathing disorder (Dixhoorn & Folgering, 2015). Dixhoorn and Folgering (2015) stated that a score of greater than or equal to 19 best differentiates individuals with a potential breathing disorder from individuals with normal breathing patterns. Therefore, if participants scored below 19, they were included in the study; however, if they scored a 19 or above, they were no longer permitted to continue. As previously stated, if a participant scored a 19 or above on the NQ with no prior diagnosis of a breathing disorder, the student researcher would have advised that they speak with a medical professional for additional testing and any concerns that he/she had regarding breathing difficulties.

The psychometric properties of the NQ showed that it is both a valid and reliable tool in the screening for hyperventilation syndrome (HVS) and for individuals with mild-to-moderate asthma (Grammatopoulou et al., 2014; Van Dixhoorn & Duivenvoorden, 1985). Go and Singh (2013) stated that individuals who experienced a mTBI have been known to spontaneously start hyperventilating resulting in decreased alveolar and blood CO_2 levels. The hyperventilation tendencies are thought to be caused by miscommunication post injury between the medulla oblongata and the medullary respiratory control center (Go & Singh, 2013). In 1985, Van Dixhoorn and Duivenvoorden explored the ability of the NQ to differentiate between individuals that have HVS and those who did not. The questionnaire yielded 93% correct classifications and was found to have a sensitivity of 91% and specificity of 95% in the clinical diagnosis. In a more recent study, Grammatopoulou et al. (2014) explored the validation of the NQ and found the questionnaire to have a 92.73% sensitivity, 91.59% specificity, high internal consistency (α=.92), and high test-retest reliability (.98). The research also showed that the NQ had a significant positive correlation between $ETCO_2$ (r=.68) and RR (r=.66). The NQ was free to access and did not require any specialized training to administer or interpret. Therefore, the accessibility, ease of use, and exceptional psychometric properties made the questionnaire an appropriate screening measure of breathing patterns in participants for this study.

Immediate Post-Concussion Assessment and Cognitive Testing®

The ImPACT® test battery is a commonly used computerized neurocognitive test designed specifically as a measure of executive function in healthy and concussed populations. Executive functioning refers to the brains ability to perform daily living functions such as learning, remembering, and processing sensory information (Cristofori et al., 2019). The computerized test consists of the participant completing a demographic profile, the PCSS, and six test modules. The modules were developed to measure different dimensions of executive functioning including visual and verbal memory, working memory, processing speed, visual-motor skills, and reaction time. Each module is further explained in the subsequent paragraph. The ImPACT® battery requires approximately 25-30 minutes to complete on a computer (Lovell, 2015). The test begins with the demographic information, this section asks participants to fill out personal information regarding his/her background and native language, education and special needs, concussion and sport background, and any relevant medical information (Lovell, 2015). Following the demographic questionnaire, participants were asked to complete the PCSS questionnaire where they were asked to accurately rate the symptoms that he/she may have experienced within the last 7 days. The PCSS is a 19-item self-report questionnaire with symptoms closely associated with concussive injuries on a 7-point Likert scale between 1 (minor) and 6 (severe). There is a positive relationship between the PCSS score and the recovery period after a concussion, as the PCSS score increases, the recovery period also increases. Therefore, the lower PCSS score, the better; a lower score represents a lower number and severity of symptoms as documented by the individual (Joyce et al., 2015).

The final section of the ImPACT® battery is divided into six modules in which each is designed to measure a different combination of executive function dimensions (Lovell, 2015). The first two modules are Word Memory (M1) and Design Memory (M2) where both modules evaluate attentional processes with M1 testing verbal recognition memory and M2 testing visual recognition memory. Both modules present 24 words or shapes respectively and asks participants to recall and correctly identify which of the items were previously shown on the screen. The next module, Xs and Os (M3) is responsible for measuring working memory and visual processing and motor speed. The third module tasks participants by asking them to correctly identify the location of three symbols after performing a distracting task. Following M3, the fourth module, Symbol Match (M4), requires participants to remember an assorted number of symbols and correctly choose their corresponding number from 1-9. The M4 is designed to evaluate visual processing speed, learning, and memory. Module number five, Colour Match (M5), asks individuals to respond as quickly as possible to identify if the colour of the writing matches the written word. This module is used to represent a choice reaction time task and measure impulse control/response inhibition. The final module is Three Letters (M6) which measures working memory and visual-motor response speed. The task for this module is to remember three letters after completing a distraction task.

The ImPACT® test has been found to have a high sensitivity (81.9%) and specificity (89.4%) when differentiating between concussed and non-concussed individuals (Schatz et al., 2006). The ImPACT® is not free to access, however, like the NQ it is easy to administer and does not require a specialist to administer or interpret (Lovell, 2015). Harmon et al. (2013) also highlighted that the ImPACT® is the most cost-effective executive functioning test, with a quick turnover for results. As previously mentioned, the ImPACT® test breaks down and evaluates skills of daily living. Skills such as visual processing speed, learning, and memory are used in every career, including the military. This is especially true in high-risk situations where superior processing speed and memory may even save a life. Therefore, based on these characteristics the ImPACT® test battery was the most appropriate option to replicate a neurocognitive task for the purposes of this study.

CapnoTrainer®

Partial pressure of CO_2 is a representative measure for the balance of CO_2 production and elimination (McLaughlin, 2014). These measures provide important information regarding metabolism, pulmonary function, and breathing patterns and behaviours. As previously stated, the gold standard for obtaining these measures is through arterial blood gases, requiring an invasive blood sample through a radial artery puncture. Since CO_2 values change on a breath-by-breath basis, this invasive and time-consuming test ultimately limits detections of poor breathing behaviours (McLaughlin, 2014). A capnography unit, however, captures continuous data with each breath and provides a more convenient and non-invasive measure of gathering the information related to breathing (McLaughlin, 2014).

The CapnoTrainer® is a portable capnography breath analyzer that was utilized in this study to measure CO_2 at the end of exhalation ($ETCO_2$) and the number of breathes per minute (RR; refer to Figure 8; McLaughlin et al., 2011). The capnography unit records expelled $ETCO_2$ and RR in a comprehensive capnogram waveform that was recorded onto a laptop computer running the CapnoLearning 4.0 PhysioLab software. This portable unit detects the CO_2 concentration in an exhaled breath by using an infrared photo detector. The unit compares the intensity of the light transmission between exhaled and non-exhaled air. Since CO_2 absorbs infrared light, the comparison between the exhaled and non-exhaled air gives a value of CO_2 based on the infrared light absorbed (McLaughlin, 2014).

Figure 8. A CapnoTrainer Capnography Breath Analyser. In Resilia, 2005, Retrieved June 21, 2017, from http://www.resilia.org/capnotrainer.html

The CapnoTrainer® provides a reliable measure in individuals with no existing breathing disorders during quiet breathing and cognitive tasks (Coleman et al., 2009). Although other equipment is often used in clinical and hospital settings to diagnose breathing disorders, the CapnoTrainer® remains a reliable and valid measure for assessing breathing physiology (Siedlecki et al., 2018). Mclaughlin et al. (2011) used the CapnoTrainer® to measure respiratory function in individuals experiencing low back pain. This study aimed to determine if respiratory dysfunction was present in individuals experiencing neck or low back pain. Additionally, the researchers examined if biofeedback training could improve breathing function, improve $ETCO_2$, and reduce pain. All participants within the study experienced improved breathing patterns, reduced pain, and improved $ETCO_2$ values. It was suggested that the CapnoTrainer® could be used as a screening measure for breathing dysfunction (Mclaughlin et al., 2011) and used as an adjunct for assessment and treatment of various pain disorders. Ultimately the CapnoTrainer® is a convenient, non-invasive, easy to administer, and effective measurement tool compared to more invasive, sophisticated, and expensive equipment and methods utilized in the hospital environment (Siedlecki et al., 2018).

Military Vest

Soldiers in the military often perform long marches that can last for up to 20 km with varying weights loaded into their ruck sacks (Johnson et al., 1995). Tenan et al. (2017) conducted a study examining ruck sack load effect on the probability of hitting a target when shooting. This study required soldiers to walk for 11.8 km with a 48.5 kg on their person with a maintained walking speed of approximately 4.3 km/hour. Tenan et al. (2017) concluded that the heavy gear carried elevated the HR of the soldiers on the march. When HR is elevated during physical activity, the demand for O_2 increases which requires the respiratory system to function at a higher rate, increasing RR and $ETCO_2$ output (Kenney et al., 2012). Although soldiers often carry weights that may exceed 65 kg, the study used the portable capnography unit, therefore, requiring the individuals to breathe through their nose for the duration of the test. If the load for participants was too heavy, it may have prevented the individual from successfully breathing through their nose. Therefore, for this study the military members were equipped with a 20 kg weighted vest. This weighted vest was used to simulate a typical training or work environment.

The rationale behind the designated weight for this was guided by the annual Fitness for Operational Requirements of Canadian Armed Forces Employment (FORCE) which every employee in the Canadian Armed Forces (CAF) must meet (CAF, 2021). This test consists of four tasks, three of which are conducted with a 20 kg sandbag used by all members, with no exceptions. The tasks include a sandbag lift, intermittent loaded shuttles, sandbag drag, and 20 m rushes. Some trades within the CAF are required to meet higher physical requirements, but the FORCE evaluation is the reflection of minimal physical employment standard that all members must meet. Based on the minimal requirements of all CAF members, 20 kg is a reasonable amount of weight that all participants within this study should be able to successfully bear for two 3-minute walking intervals without issue (CAF, 2021).

COVID-19 Precautions

Having addressed the concerns regarding the ongoing pandemic, participants were required to be fully vaccinated in order to participate in the study. Being fully vaccinated is defined by the Ministry of Health in Ontario as an individual who has received the full series of a COVID-19 vaccine authorized by Health Canada, or a combination of vaccines (Ministry of Health, 2021). All data collection was conducted from 1.8 m apart when possible. The student researcher and participant washed their hands prior to the data collection and hand sanitizer was available throughout, as required. Data collection was one-on-one and scheduled to avoid any grouping of more than two individuals in a room at one time. The participant was instructed on how to properly place the single-use nasal cannula and did so independently. The participants did not wear their mask over the nasal cannula to avoid affecting the results of the data. The only time the student researcher and participants were closer than 1.8 m was when the student researcher was spotting the participants on the treadmill for the physical walking task. Participants were asked to complete the current screening requirements set in place by the local health unit. The student researcher confirmed with the participants that their contact information may be used for contact tracing, if necessary.

Procedures

Data Collection

Participants that qualified for inclusion into the study were invited to take part in a single session, lasting between 45-60 minutes, whereby participants took part in three tasks supervised by the student researcher. Data collection took place at the Heritage Fitness Centre in Carleton Place. Prior to the first task, participants were provided with an information letter and given the opportunity to ask questions concerning the study. Participants were informed that they were permitted to withdraw from the study at any time prior to data collection. Data collection was also stopped if any of the participants began to experience any severe symptoms (i.e., breathing, concussion related, or otherwise). Participants were also instructed to avoid speaking unless necessary (i.e., safety concerns) during data collection as talking has been known to alter the capnography results (Siedlecki el al., 2018). Due to the use of the capnography unit, participants were instructed to breathe through their nose for the entire data collection process as the CapnoTrainer® collected data through a nasal cannula.

After the introductory phase of the study was completed and all questions and concerns were addressed, a consent form was then available for the participant to complete. Once written consent was obtained, a demographic interview was conducted by the student researcher. General information about the participant was recorded during this process including the participant's year of birth, history of previous concussions, knowledge of breathing disorders, and branch of the military (see Appendix F). Objective measurements of the participant's mass (kg) and height (cm) was then measured and recorded by the student researcher. Participants were then be asked to complete the NQ. The NQ was used to identify the types of breathing patterns utilized by the participant as well as ensure participants fell within the normal range (below 19) so that they could continue with the study. After the screening measures and forms were completed, the CapnoTrainer® capnography breath analyzer was connected to and calibrated with a laptop computer running 4.0 PhysioLab software. Participants were instructed about what the device measured and fitted with a single-use nasal cannula, which was connected to the CapnoTrainer®. The nasal cannula was worn by the participant throughout the entire testing process. Participants were instructed to breathe through their nose while wearing the nasal cannula. Participants were also instructed to avoid speaking, snorting, or laughing as it would affect the $ETCO_2$ measures. If participants required the researcher's attention, they were instructed to wave or to tap the researcher on the shoulder if they felt comfortable. The CapnoTrainer® was then turned on, permitting the device to warm-up prior to beginning the neurocognitive task.

Neurocognitive Task

Following the setup of the CapnoTrainer®, the participant was fitted with their single use nasal cannula and baseline information and physiological data about the participant's breathing pattern was collected via the CapnoTrainer®. Resting $ETCO_2$ levels (mmHg) and RR (breaths/min) were recorded during quiet breathing while the participant was sitting upright in a chair for 40 s. These 40 s were used to ensure the CapnoTrainer® had enough time to warm up and to avoid any prospective measurement error during the task.

For the first task, the participant was asked to complete the ImPACT® neurocognitive test battery. The ImPACT® neurocognitive test was completed in a quiet, well-lit room, and void of any distractions. The test measured the different dimensions of executive functioning including visual and verbal memory, working memory, processing speed, visual-motor skills, and reaction time. To track progression through the neurocognitive task, event markers were inputted on the CapnoLearning software when each module was started. Following the completion of the ImPACT® battery, the participant was provided a 2-minute rest period to allow any physiological changes to ventilation to normalize and to avoid having this affect the data for the preceding task. Breathing patterns are expected to return to normal resting values within 45 s on average following mild intensity exercise in healthy individuals (McLaughlin, 2014). If the participant needed an extended break period to return to similar baseline values, then it was accommodated and recorded as it is important to return to normal baseline levels before moving on to the physical walking task to ensure the measures are accurate (Siedlecki et al., 2018). None of the participants recruited for this study required extended rest periods or unscheduled breaks.

Physical Task

After the rest break, baseline values were collected again for $ETCO_2$ and RR with the participant standing upright on the treadmill for 40 s. The participant's baseline values were recorded for a second time as gravity can influence the body's respiratory response and subsequently affect the $ETCO_2$ and RR measures (Siedlecki et al., 2018). The second task involved the participant walking on a treadmill at two different walking speeds. Each trial lasted 3-minutes and was followed with a 2-minute rest break afterward (or longer, if required). Participants were notified when there was 1-minute remaining and when there were 10 s remaining in each trial. This walking task was selected to replicate daily living activities for individuals who are currently working in the military. The timeframe for the task was selected due to the expected plateaus for $ETCO_2$ values at approximately 2-minutes during exercise at a constant intensity (Siedlecki et al., 2018). Prior to commencement of the first walking trial with the weight vest, the participant was reminded that they could stop the treadmill at any time should problems arise. The graduate student acted as a spotter and was also present to prevent any problems from occurring.

The first walking trial consisted of the participant walking at a slow, self-selected speed between 4.8 and 5.5 km/h with the treadmill elevation positioned at a .5% grade. The speed was chosen by the participant within the range provided to resemble his/her average walking speed. The .5% incline provided a more realistic representation of walking outdoors. When walking on a treadmill indoors, there is a lack of air resistance and lower energy cost (Jones & Doust, 1996). Pind et al. (2019) conducted a study comparing the metabolic differences between running on a track compared to a treadmill at a 1% incline. Results of this study showed an increased O_2 consumption and a caloric cost when running on the treadmill as compared to an outdoor track (Pind et al., 2019). The researchers suggested that the 1% incline on the treadmill surpassed the O_2 consumption and energy expenditure compared to running outdoors. Therefore, 1% is not necessarily an adequate representation of being outdoors (Pind et al., 2019). To avoid overexerting the participants for the study, an incline of .5% was chosen. This incline was chosen to provide a reasonable comparison to air resistance when walking outside but to avoid forcing the participants to breathe through their mouths.

The military members were equipped with a 20 kg weighted vest as they are highly physically and psychologically trained. The weighted vest used for this study had 20 kg evenly distributed between the front/back and left/right sides. The vest consisted of a black fabric with slots for weighted bars to be inserted or removed. Each bar weighed 1 kg. Ten bars were distributed over 10 pockets across the front of the vest and 10 bars were distributed across the back of the vest. Additionally, when placed over the head and shoulders the straps across the waist were secured tightly by the participant and, then, if necessary, adjusted by the researcher. This weighted vest was used to simulate a standard work environment for these individuals. Looney et al. (2021) conducted a study on modern military and backpack loads having the participants walking at the lowest speed of 1.62 km/h and a maximum speed of 7.09 km/h while equipped with the lightweight pack along with bumper plates, ankle weights, and hard foam for stabilization. Therefore, the maximum and minimum boundaries were developed based on prior research on average walking speed and walking in the military with a weighted vest (Carey, 2005; Looney et al., 2021).

The second walking trial required the participant to walk at a speed that is 25% faster than the walking speed he/she chose during the first walking trial at a treadmill elevation positioned at a .5% grade. The 25% increase in walking speed was chosen to increase the physical stress on the participants; ideally the increase in physical stress would in turn reproduce any respiratory differences between the healthy and concussed groups. The 25% increase was modeled using Siedlecki et al. (2018) and Siedlecki et al. (2017), the researchers used similar walking speeds and found that the 25% increase was reasonable in terms of physical stress load. This speed increase provided the ability to maintain a walking pace and avoid overwhelming individuals in a potentially at-risk population. Depending on the speed chosen for the first trial, the participant's walking speed ranged from 6.0 km/h to 6.8 km/h for the second walking trial. Siedlecki et al. (2018) proceeded with an initial range of values of 4.8 km/h to 5.6 km/h increasing to a range from 6.1 km/h to 7.1 km/h. The participants in Siedlecki et al's study stated that the speed for the second trial became too fast to maintain and to continue to breathe through the nose only (Siedlecki et al., 2018). It is important, however, to keep in mind that the individuals recruited for this study had basic minimum requirements to become a military member. Since the individuals were required to meet a certain standard of physical fitness, the walking speed was not modified. During the 2-minute rest breaks, the speed of the treadmill was slowly decreased so that the treadmill came to a complete stop so that the participant could rest in an upright standing position. Following the final rest period, the nasal cannula was removed, the participant was thanked for their participation, and were able to leave.

Data Analysis

Data analysis was completed using the executive functioning scores and breathing physiology data collected using the CapnoTrainer© and the ImPACT®. The data was promptly exported into Microsoft® Excel's computerized program for primary analysis. Statistical analysis was completed with IBM® SPSS® 24. The statistical software was used to investigate the interaction effect between groups (healthy versus concussed) and task (physical versus neurocognitive) on the dependent variables, $ETCO_2$ levels and RR. Two groups (concussed versus healthy) X three conditions (physical task at normal speed, physical task at 25% higher speed, and neurocognitive task) mixed factorial ANOVAs were conducted on measures of $ETCO_2$ levels and RR, respectively, to address questions 1 and 2. No interactions were found between groups and conditions for measures of $ETCO_2$ levels or RR, therefore, the main effect analyses were performed. To address question number 3, an independent samples t-tests was conducted to compare the mean values of the executive functioning variables (verbal memory, visual memory, visual motor speed, reaction time and impulse control) between healthy versus concussed military members. Bonferroni corrections were implemented to account for the entire variance of the executive function variables and minimize the chance of committing type I error in the analysis at $p<.05$.

Chapter 4

Results

The purpose of this study was to examine differences between healthy and concussed military members on measures of ETCO$_2$ and RR when completing a neurocognitive task (ImPACT®) and a physical task (walking on a treadmill with a weighted vest). This study also aimed to examine differences between healthy and concussed military members on executive functioning scores when completing a neurocognitive task (ImPACT®).

Descriptive Statistics

Thirty healthy (n=17) and concussed (n=13) active Canadian Military Members completed the study. The demographic characteristics for the participants are summarized in Table 3. An independent sample t-test was conducted with an alpha level set to *p*=.05 to compare the PCSS data between the concussed and healthy military members. The PCSS score between the two groups was found to be statistically significant (*p*=.024, *d*=.881). The PCSS scale gave the individual the ability to self-score symptoms that are consistent with a concussive injury (Joyce et al., 2015). The higher the reported score, the higher the number of symptoms, and greater the severity that individual is experiencing. Therefore, the findings indicated that there was a statistically significant difference with a large effect size between the concussed (M=22.92, SD=4.40) and healthy individuals (M=12.05, SD=2.61) when evaluating the scale presented during the ImPACT® test, *t*(28)=2.392, *p*=.024, *d*=.881. This means that the higher scores reported by the concussed group on the PPCS may have confirmed that the individuals in that group were experiencing a higher number and severity of symptoms as compared to the healthy group. The large effect size for the PCSS scores supports the statistically significant finding, showing that there is a substantial difference between the two groups.

Table 3

Demographic characteristics of participants (Mean ± SD*)*

Group	**Age (yr)**	**Gender**	**Mass (kg)**	**Height(cm)**	**NQ Score**	**Division**	**PCSS***
Healthy (n=17)	38.41 (±9.72)	Males=15 Females=2 Other=0	83.71 (±12.45)	176.24 (±7.03)	6.47 (±3.76)	Army=14 Navy=2 Airforce=1	12.05, (±2.61)
Concussed (n-13)	35.38 (±7.12)	Males=9 Females=4 Other=0	84.03 (±13.26)	175.07 (±7.91)	10.07 (±4.83)	Army=9 Navy=1 Airforce=3	22.92, (±4.40)
Total (n=30)	37.10 (±8.86)	Males=24 Females=6 Other=0	83.85 (±7.323)	175.74 (±7.32)	8.03 (±4.56)	Army=23 Navy=3 Airforce=4	16.76 (±13.29)

* Indicates significant differences between the groups (*p*=0.05)

No statistically significant findings were identified for participant age (*p*=.091), mass (*p*=.730), height (*p*=.619), or NQ score (*p*=.195). No statistically significant differences for age, mass, and height indicated that the groups had similar mean values, and this outcome provided evidence that that two groups were homogeneous for the measures of these variables. The NQ scores in the concussed (M=10.07, SD=4.83) as compared to the healthy group (M=6.47, SD=3.76) were not statistically different. The NQ gave the individuals the opportunity to score any dysfunctional breathing symptoms they may have been experiencing (Dixhoorn & Folgering, 2015). The absence of statistically significant differences indicated that both groups had similar NQ mean values, and likely did not suffer from a breathing disorder or dysfunction.

Question 1. ***What were the effects of a physical task (walking while wearing a weighted vest) compared to a neurocognitive task (ImPACT®) on ETCO2 in healthy versus concussed military members?***

Descriptive Statistics. The descriptive statistics on $ETCO_2$ were collected while participants sat quietly completing the ImPACT® test and while walking on a treadmill at an average walking speed and then 25% faster. These statistics can be found in Table 4. The descriptive statistics presented below show that the mean values fell within the normal range for $ETCO_2$, generally between 35-45 mmHg (Braun,1990; Mclaughlin, 2014). The data shown in Figure 9, provides a clear trend, showing that the $ETCO_2$ values increased over the three tasks with a slightly higher mean value observed for the concussed group across each of the tasks compared to the non-concussed group.

Table 4

$ETCO_2$ in healthy versus concussed military during a physical and neurocognitive task

Task	Healthy	Concussed
Slow walk	M= 36.7412, SD= 4.29396	M= 37.2603, SD= 3.33088
Fast Walk	M= 37.9100, SD= 3.89402	M= 38.3638, SD= 4.01832
Impact Test®	M= 36.0969, SD= 2.60964	M= 36.9415, SD= 4.40976

M=mean; SD= standard deviation

Interaction effect. The Huynh-Feldt degrees of freedom values were utilized because the assumption of sphericity was violated $\chi^2(2)=6.099$, $p=.047$. The two-way mixed factorial ANOVA revealed no statistically significant interaction effect between the two groups (healthy and concussed military members) and the three tasks (ImPACT® test and walking with a weighted vest) on measures of $ETCO_2$, $F(1.819, 50.935)=.106$, $p=.882$, partial $\eta2=.004$. The very small effect size supports the notion that both concussed and healthy military members produced similar mean ETCO$_2$ values for the physical and neurocognitive tasks (refer to Figure 9).

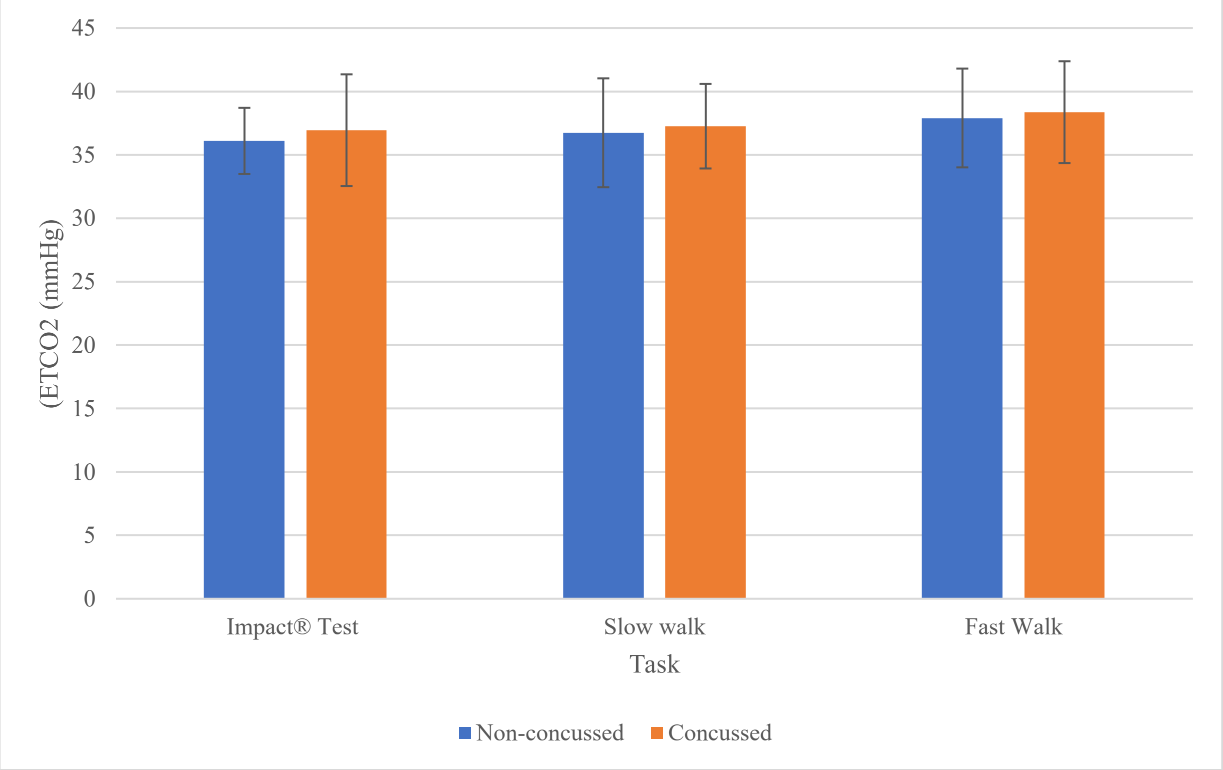


Figure 9. Mean comparison of ETCO$_2$ (mmHg) between groups (concussed versus healthy military members) across three tasks (ImPACT® concussion test, slow walk, and fast walk).

Main effects. The main effect on task showed that there was no statistically significant difference in mean ETCO$_2$ for concussed and healthy military members $F(1, 28) = .732$, $p = .399$, partial η2=.025. The small effect size emphasized that both groups produced similar mean ETCO$_2$ values over physical and neurocognitive tasks. Similarly, the main effect on group showed that there was no statistically significant difference in mean ETCO$_2$ between concussed and healthy military members $F\ (1, 28) = .219$, $p = .643$, partial η2=.008. The very small effect size supports the finding that both the concussed and healthy military members produced similar mean ETCO$_2$ values for all three tasks.

Question 2. ***What were the effects of a physical task (walking while wearing a weighted vest) compared to a neurocognitive task (ImPACT®) on RR in healthy versus concussed military members?***

Descriptive Statistics. The descriptive statistics on RR were collected while participants sat quietly completing the ImPACT® test and while walking on a treadmill at an average walking speed and a speed 25% faster. These statistics can be found in Table 5.

Table 5

RR in healthy versus concussed military during a physical and neurocognitive task

Task	Healthy	Concussed
Slow walk	M=20.1071, SD=4.29036	M=21.0485, SD=3.53415
Fast Walk	M=20.8064, SD=4.52145	M=21.6254, SD=4.11787
Impact Test®	M=16.9057, SD=2.75806	M=17.0239, SD=2.91745

M=mean; SD= standard deviation

Interaction effect. Mauchly's test of sphericity revealed that the assumption of sphericity was violated $\chi^2(2)=10.068$, $p=.007$ and, therefore, the Huynh-Feldt degrees of freedom values were utilized. The two-way mixed factorial ANOVA revealed no statistically significant interaction effect between the two groups (concussed and healthy military members) and the three tasks (ImPACT® test and walking with a weighted vest) on measures of RR, $F(1.653, 46.279)=.205$, $p=.773$, partial η2=.007. The small effect size supports the findings that both concussed and healthy military members produced similar mean RR values for the physical and neurocognitive tasks (refer to Figure 10).

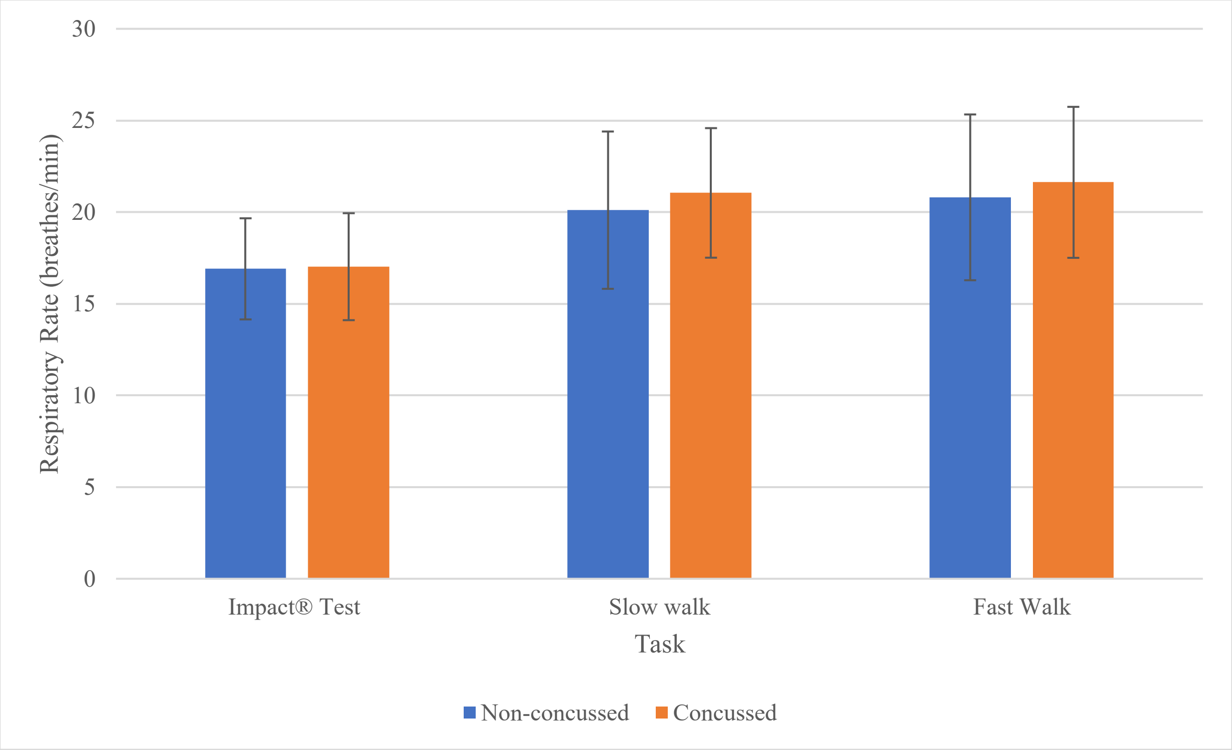


Figure 10. Mean comparison of RR (breaths/min) between groups (concussed versus healthy military members) across three tasks (ImPACT® concussion test, slow walk, and fast walk).

Main effects. The main effect on task showed that there was no statistically significant difference in mean RR for concussed and healthy military members *F*(1, 28) =.172, *p*=.682, partial η2=.006. The very small effect size supports that both groups produced similar mean RR values for the physical and neurocognitive tasks. The main effect on group showed that there was no statistically significant difference in mean RR between concussed and healthy military members *F*(1, 28)=.302, *p*=.587, partial η2=.011. The small effect size strengthens the finding that both the concussed and healthy military members produced similar mean $ETCO_2$ values for all three tasks.

Question 3. ***Was there a difference in executive functioning scores during the completion of the ImPACT® neurocognitive test between healthy versus concussed military members?***

Descriptive Statistics. The descriptive statistics on the ImPACT® were collected while participants sat quietly completing the computer-based test. These statistics can be found in Table 6. The executive functioning scores were similar with only a small difference between verbal memory in the healthy (M=85.88, SD=9.59) and the concussed group (M=82.38, SD=11.98). The difference in verbal memory showed that individuals in the healthy group had an easier time with word recall. Additionally, there appeared to be a small difference observed between the visual motor speed between the healthy group (M=34.60, SD=4.80) and their concussed counterparts (M=36, SD=6.80).

Table 6

Impact Scores in healthy versus concussed military members

Task	Healthy	Concussed
Verbal Memory	M= 85.88, SD= 9.59	M= 82.38, SD= 11.98
Visual Memory	M= 71.00, SD= 12.82	M= 70.69, SD= 12.36
Visual Motor Speed	M= 34.60, SD= 4.80	M= 36.00, SD= 6.80
Reaction Time	M= .695, SD= .0728	M= .681, SD= .107
Impulse Control	M= 3.88, SD= 2.23	M= 3.76, SD=2.80

M=mean; SD= standard deviation

Group Effect. Independent-samples t-tests were conducted to examine differences in executive function scores between concussed and healthy military members. Levene's test for equality of variances revealed that the two groups were homogenous (p> .05). The results, however, did not reveal a statistically significant difference between concussed (M=85.88, SD=9.59) and healthy participants (M=82.38, SD=11.98) for verbal memory scores, *M* = -3.49, 95% CI [-11.5, 4.60], *t*(28)=-.889, *p*=.356, *d*= -.327. Healthy participants (M=71, SD=12.82) did not have a statistically significant higher score than the concussed participants (M=70.69, SD=12.36) for visual memory, *M* = -.307, 95% CI [-9.83, 9.22], *t* (28)=-.066, *p*=.906, *d*= -.024. A statistically significantly lower score was not determined for concussed participants (M=36, SD=6.80) as compared to healthy participants (M=34.60, SD=4.80) for visual motor speed, *M* = 1.40, 95% CI [-2.93, 5.74], *t*(28)=.664, *p*=.299, *d*= .245 (refer to Figure 11). Similarly, there was no statistically significant difference found between the concussed group (M=.681, SD=.107) and healthy group (M=.695, SD=.0728) for reaction time, *M* = -.014, 95% CI [-.081, .053], *t*(28)=-.435, *p*=.292, *d*= -.160. Finally, there were no statistically significant findings between concussed (M=3.76, SD=2.80) and healthy participants (M=3.88, SD=2.23) for impulse control *M* = -.113, 95% CI [-1.99, 1.76], *t*(28)=-.123, *p*=.679, *d*= -.045 (refer to Figure 12). The small effect sizes support the findings that both the concussed and healthy military members produced similar mean verbal memory, visual memory, visual motor speed, reaction time, and impulse control composite scores over the neurocognitive task.

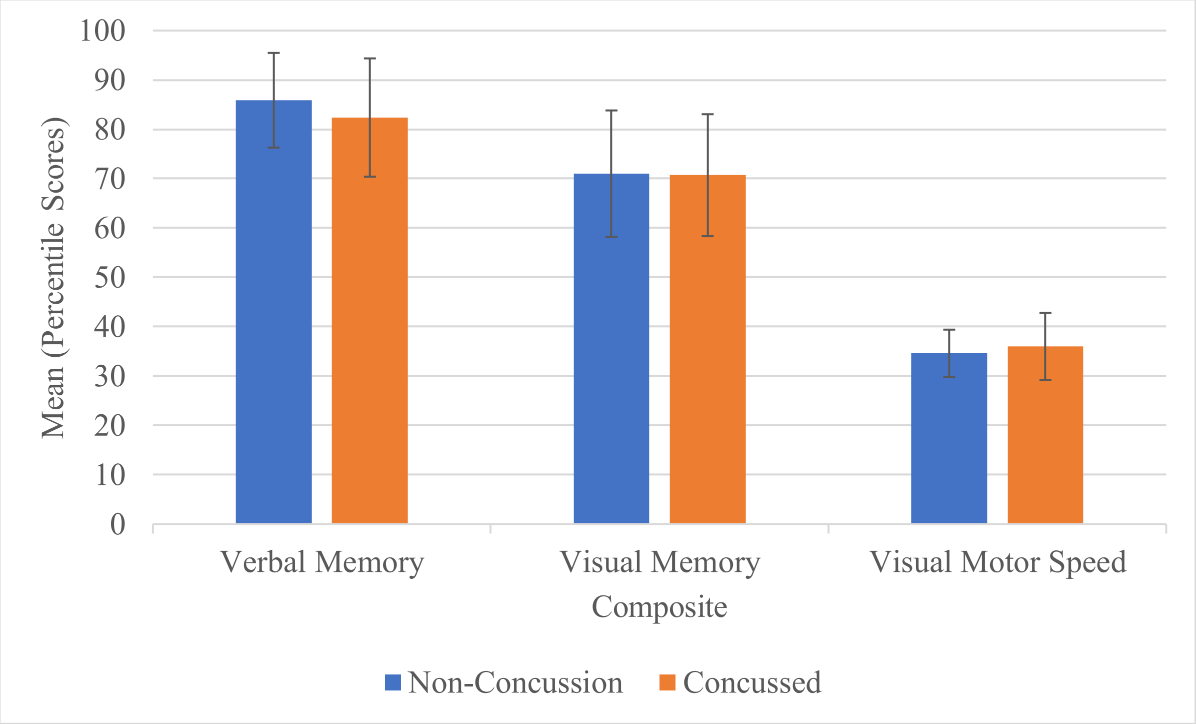


Figure 11. Mean comparison of verbal memory, visual memory, and visual motor speed composite scores of the ImPACT® concussion test between groups (concussed versus healthy military members).

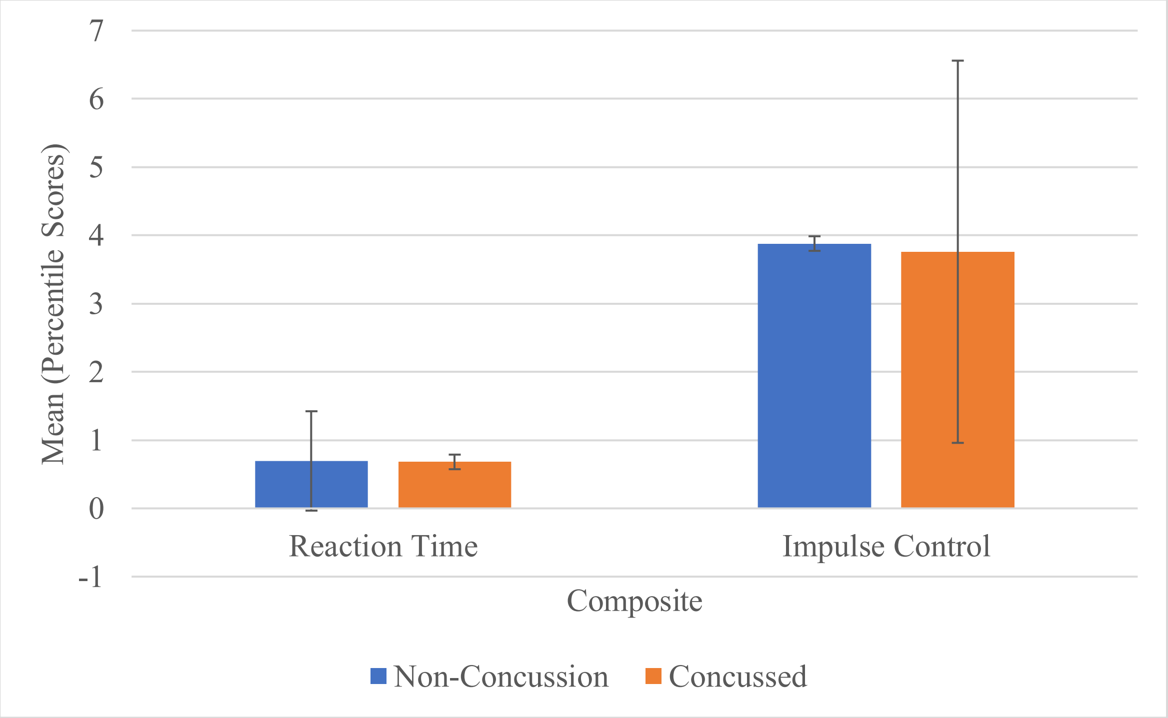


Figure 12. Mean comparison of reaction time and impulse control composite scores of the ImPACT® concussion test between groups (concussed versus healthy military members).

Chapter 5

Discussion

This was one of the first studies that measured $ETCO_2$ and RR in relation to how breathing patterns change when completing tasks that mimic day to day cognitive and physical efforts in healthy versus concussed Canadian military members. This study was one of few that measured executive functioning scores, $ETCO_2$, and RR when completing tasks that mimic day to day cognitive and physical efforts in military members. The significance of this study's results will contribute to limited literature that explores the possibility that abnormal or dysfunctional breathing patterns may exist in individuals who have previously suffered a concussion and are part of Canada's military forces. Therefore, further research is warranted, due to the prevalence of brain injuries that occur during training and combat.

Question 1. ***What were the effects of a physical task (walking while wearing a weighted vest) compared to a neurocognitive task (ImPACT®) on $ETCO_2$ in healthy versus concussed military members?***

There were no statistically significant differences found in $ETCO_2$ measures when comparing healthy versus concussed military members after completing a physical task or a neurocognitive task. Although there was no statistical significance found, the mean $ETCO_2$ values were slightly higher for the concussed group across each of the tasks when compared to the healthy group. Normal resting measures for $ETCO_2$ generally land between approximately 35-45 mmHg and it is not abnormal when these values reach over 40 mmHg (Braun,1990; Hoshimoto-Iwamoto et al., 2009; Mclaughlin, 2014). The ImPACT® test was used to create a cognitive stress load for the participants in order to identify and/or reproduce breathing dysfunctions or abnormal behaviors. End-tidal CO_2 values were tracked for all participants while completing the physical and neurocognitive tasks to establish if there were any differences between the concussed and healthy military members. The $ETCO_2$ values during this task were well within the normal range for both groups. Alternatively, the slow and fast walk were used to create a physical stress load for participants. Each of the respective tasks put different types of workloads and stressors on the body to identify any differences in breathing measures. Across both physical tasks, $ETCO_2$ values were within the normal range for each group. However, like the neurocognitive task, the $ETCO_2$ values for the concussed group appeared to be also slightly elevated as compared to the healthy group for both the slow and fast walk.

Breathing dysfunctions such as agonal breathing (i.e., slow, shallow, and irregular breaths) have been linked to certain types of brain injuries (Whited & Graham, 2021). Similarly, individuals who experienced a mTBI have been known to spontaneously start hyperventilating resulting in decreased alveolar and blood CO_2 levels (Go and Singh, 2013). Hyperventilation in these individuals is thought to be caused by miscommunication, post injury, between the medulla oblongata and the medullary respiratory control center (Go & Singh, 2013). Although the differences are not statistically significant, the slightly elevated $ETCO_2$ values in the present study may be a result of HVS or other potential breathing disorders caused by an injury to the medullary or pontine respiratory groups (Go & Singh, 2013). It may also be possible that during the acute phase of an injury, individuals may have been suffering from HVS or breathing abnormalities/dysfunctions, and, therefore, in the 2-12 months post injury there could be lingering symptoms. The small difference between the healthy and concussed groups could also be attributed to other factors that have been known to effect breathing such as feelings of anxiety or an anxiety disorder (Whited & Graham, 2021).

Siedlecki et al. (2018) evaluated the interaction between groups, PPCS versus healthy participants, and event, rest versus task, on $ETCO_2$. Siedlecki et al. (2018) compared the total average $ETCO_2$ values at rest, over each module of the ImPACT® test, and over two different walking speeds. The methodological approach for the present study was based on procedures described by Siedlecki et al. (2018). The present study was structured similar to Siedlecki et al. (2018) based on the strong rationale that supports the potential risk of breathing abnormalities in concussed individuals depending on the area of the brain that was affected by the injury (i.e., the respiratory control centres). Siedlecki et al. (2018) developed a methodology that took individuals through physical and neurocognitive tasks to establish if breathing abnormalities were present in daily living activities. The methodology was modified slightly to better replicate daily living and working tasks for CAF members.

Siedlecki et al. (2018) recruited 17 healthy and 5 concussed individuals (9 males and 13 females) between the ages of 16-29 years (M= 22.3 years, SD= 2.5). Whereas the present study recruited 17 healthy and 13 concussed individuals (24 males and 6 females) between the ages of 22-59 years (M= 37.10 years, SD= 8.86). The difference in sample size, and specifically the small, affected group, could have potentially affected the results for Siedlecki et al. (2018). Having a small sample size may not accurately represent the concussed group that is being investigated and reduces the generalizability of the results across all individuals that have sustained a concussion and effect or lack of an effect on breathing. A much larger sample of concussed individuals needs to be examined and included in future studies, but the preliminary results of these studies support further examination into this area. The instrumentation and screening measures for both studies included the NQ, CapnoTrainer®, ImPACT® test, and similar walking speed intervals. In the present study baseline values were collected prior to beginning each task; however, the values were not evaluated in the analyses. More specifically, the primary focus of the present study was to compare $ETCO_2$ values between the two groups over the neurocognitive and physical tasks rather than at rest. During physical activity, RR and $ETCO_2$ values were expected to climb due to the increased energy expenditure and increased O_2 demands. The increased RR occurs as the body burns through the existing energy stores located within the muscles and the increased uptake provides the muscles the O_2 required to convert available glucose into ATP (Kenney et al., 2012). During neurocognitive tasks when individuals are highly focused, aspects of their breathing will change to accommodate for the cognitive processes that are occurring, typically resulting in decreased $ETCO_2$ (Grassmann et al., 2016). For the present study, individuals in both groups fell within normal $ETCO_2$ range and had no statistically significant differences during the neurocognitive task. It was observed, however, that individuals in the concussed group had slightly elevated $ETCO_2$ values. Additionally, the participants of the present study worked exclusively with the members of the CAF, whereas Siedlecki et al. (2018) only included civilians in their research.

Siedlecki et al. (2018) found statistically significant differences for the $ETCO_2$ values between the two groups during the ImPACT® test. The researchers found that individuals in the PPCS group had higher $ETCO_2$ values during the neurocognitive task. Although the values had a statistically significant difference, it is important to note that Siedlecki et al. (2018) stated that the PPCS groups values still fell within the normal range. Similarly, Siedlecki et al. (2018) identified significant differences between the two groups while completing the physical task. Individuals that belonged to the PPCS group, had higher $ETCO_2$ values as compared to the healthy controls during the same task. Siedlecki et al. (2018) expected this result due to the increased O_2 consumption during the physical activity which leads to an increased $ETCO_2$ value. Unlike the neurocognitive task, the mean $ETCO_2$ values for the physical task (walking at different speeds) as observed in the PPCS group were outside what is typically considered a healthy range of values.

Siedlecki et al. (2018) also observed statistically significant different $ETCO_2$ measures when comparing resting versus neurocognitive and physical task values. As anticipated, the $ETCO_2$ values significantly decreased from resting values over five of the modules for the neurocognitive task for both groups. However, it should be noted that Siedlecki et al. (2018) found no statistically significant differences between resting values and the first two modules for the ImPACT® (Word Memory [M1] and Design Memory [M2]).

Although the methodology for the present study was similar to Siedlecki et al. (2018), the results for $ETCO_2$ were not. While Siedlecki et al. (2018) found statistically significant findings between the two groups, the present study did not. This lack of significance may indicate that the concussed individuals recruited for the present study may not have suffered an injury specifically to the respiratory control centers in the brain resulting in no statistically significant difference in $ETCO_2$ values as compared to their healthy counterparts. The values observed by both studies, however, from an observational perspective seemed to show increased $ETCO_2$ values for the concussed individuals across all tasks. This may support the fact that although there is no statistical significance, from a clinical perspective, individuals who have had a concussion within the last 12 months, may produce increased $ETCO_2$ values compared to healthy individuals (Siedlecki et al., 2018).

Snyder et al. (2021) compared the $ETCO_2$, RR, SaO_2, and HR values in healthy youths compared to participants who were experiencing PPCS. The researchers identified that $ETCO_2$ values were statistically significantly lower for the PPCS group at rest compared to the healthy control group at rest. Snyder et al. (2021) developed inclusion/exclusion criteria in order to clearly differentiate the healthy control group from the PPCS group. It is interesting to note that Snyder et al. (2021) found that the PPCS participants experienced hypocapnia, decreased $ETCO_2$ values, whereas Siedlecki et al. (2018) found that the PPCS participants were experiencing hypercapnia, elevated $ETCO_2$ values (Rawat et al., 2022; Sharma et al., 2022). The discrepancy between the two studies may have been developed via methodological differences, for example, performing neurocognitive and physical tasks versus solely collecting resting values.

Contrary to Snyder et al. (2021), the present study did not include SaO_2, and HR values and primarily focused on examining $ETCO_2$ values over physical and cognitive workloads. The methodology of Snyder et al. (2021) differs greatly from the present study. Snyder et al. (2021) recruited youths between the ages of 13-25 years, whereas the present study recruited adults between the ages of 18-59 years of age. Puberty typically occurs between 8 to 13 years in females and 9-14 years in males, although for some individual's puberty may not occur until 16 years of age or later (Tang et al., 2022). There are typically no significant differences between injury characteristics, and the type of symptoms for concussive injuries between adults and children (Corti et al., 2019). As for neurocognitive functioning and symptom recovery, children who are 13-16 years have significantly longer recovery period as compared to individuals who are 18-22 years (Zuckerman et al., 2012). Additionally, from a breathing perspective, the lungs typically mature by the age of 20-25. Therefore, based on the structural and developmental differences between adults and children the results of Snyder et al. (2021) study may have been impacted (Sharma & Goodwin, 2006).

The age range of the present study was chosen to ensure that all participants were not going through any major developmental phases. The methodological differences could be a contributor to the differences found between the two studies. Snyder et al. (2021) recruited 12 healthy individuals and 13 concussed individuals (10 males and 15 females) between the ages of 13-25 years (M= 17.32 years, SD= 2.49). Snyder et al. (2021) found statistically significant decreases in $ETCO_2$ at rest, the present study observed higher $ETCO_2$ values over the neurocognitive and physical tasks between groups that was not statistically significant.

No statistically significant results were identified in the present study was not expected due to the neurometabolic and physiological changes that can impact concussed individuals as compared to their healthy counterparts (Mckee & Robinson, 2014). Based on the existing literature, it was hypothesized that a statistically significant difference between the two groups would occur when performing either a neurocognitive or physical task on $ETCO_2$ (Siedlecki et al., 2018). The discrepancy in the results as compared to existing literature could be attributed to several factors; for example, differences in the inclusion/exclusion criteria used, civilian versus military participants, and/or sample size. The inclusion/exclusion criteria regarding the healthy control group were not specified by Siedlecki et al. (2018) in regard to previous concussive injuries. However, Snyder et al. (2021) included individuals who had not sustained a concussion within the last 12 months or were experiencing PPCS from a previous injury. The present study included a group of healthy individuals who had not sustained a concussion within 24 months of data collection. The sample that was recruited for the present study included exclusively CAF members; all the individuals have been exposed to repetitive concussive injuries through acceleration, deceleration, rotational, and blast injuries in daily training and war zones (Mullally, 2017). This could have an effect on the results as there is a potential for plasticity in the neurological system and possibly permanent long-term neurological deficits and changes in brain chemistry after repetitive concussive injuries (Bieniek et al., 2015; Musumeci et al., 2019). These neurological deficits could potentially lead to dysfunctional breathing or impaired executive functioning and, therefore, limit the difference between the healthy group and the concussed groups data.

Although Snyder et al. (2021) and Siedlecki et al. (2018) identified statistically significant differences between the healthy and concussed groups, the recorded $ETCO_2$ values were still within the normal range of 35-45 mmHg at rest and after participants completed the neurocognitive task (Braun, 1990; Mclaughlin, 2014). Siedlecki et al. (2018) also reported that $ETCO_2$ in some participants that existed outside of the normal range of values, which may have indicated there were some potential breathing abnormalities in those individuals while performing a physical walking task. This highlights that breathing may be impacted in some individuals, but it may be task specific where the intensity, speed, and/or duration of the task stresses the group enough to challenge their breathing physiology.

Question 2. ***What were the effects of a physical task (walking while wearing a weighted vest) compared to a neurocognitive task (ImPACT®) on RR in healthy versus concussed military members?***

The findings of the present study supported the null hypothesis, that when comparing the healthy and concussed military members there was no difference between the RR values when under a physical or cognitive stress load. As stated previously, the ImPACT® test was primarily used to create a cognitive workload for the individuals participating in the study. When examining the healthy and concussed individuals RR during the ImPACT® test, it was observed that the measures were both within the average range of normative values. The normal resting range of RR is typically between 12-20 breaths per minute (Hill & Annesley, 2020). The healthy group recorded a mean value of 16.9 breaths/minute and the concussed group recorded 17.02 breaths/minute. It is interesting to note that both groups were on the higher side of the range of values for RR, this may be due to the physiological response to cognitive stress load, where the brain requires an increased amount of O_2 to perform executive functioning tasks (Cobley et al., 2018). Similar results were observed for participants after completing the physical task (walking with a weighted vest), over the duration of the slow and fast walk as there was a steady increase in RR values. Over the physical tasks, RR was slightly above the average resting rate values which was expected as O_2 demand increases as physical demands increase (Kenney et al., 2012). Although there was no statistically significant difference between the two groups, the trends in the data showed that concussed individuals had consistently higher RR values over all three tasks. Similarly, to the increased $ETCO_2$ values in the concussed individuals, increased RR values may indicate potential breathing abnormalities associated with concussive injuries. This increase in RR may mean that the cognitive and physical stress load may have been causing the concussed group to work harder. In severe cases, the increased workload could potentially lead to respiratory fatigue and a decreased amount of O_2 being consumed (Johnson et al., 1996). A lower concentration of O_2 could potentially impair neurocognitive and physical performance.

While monitoring $ETCO_2$ Siedlecki et al. (2018) simultaneously evaluated the differences in RR. Siedlecki et al. (2018) compared the average RR values at rest, over each module of the ImPACT® test, and over the two different walking speeds. The researchers did not identify any statistically significant differences when examining the RR values between the two groups during any of the tasks. Both groups' values fell well within the normal range for RR when completing the tasks. Siedlecki et al. (2018) did, however, observe statistically significant differences when comparing the resting RR values to task specific RR values for both the neurocognitive and the physical tasks. The RR values significantly increased from resting values over the neurocognitive task for both groups. During the physical task, the RR values significantly increased compared to the values collected at rest. Over the duration of the slow and fast walking task, RR values steadily rose as the walking speed increased. This result was expected due to the increased O_2 consumption during physical activity. As previously stated, Siedlecki et al. (2018) and the present study have many similarities. When examining RR, neither of the studies reported statistically significant differences between the two groups after completing a physical or a neurocognitive task. Both studies did observe slightly elevated RR values for the concussed group as compared to the healthy group. The similarities in RR may be due to the physiological changes that occurred when completing a physical versus a neurocognitive task. The slight difference between the healthy and concussed groups for RR may have been caused by mild symptom reproduction in the concussed individuals over the tasks. It may also be attributed to other potential differences and confounding variables such as differences in physical fitness levels, cigarette smoking status, feelings of anxiety, or the presence of seasonal allergies (Cheng et al., 2003; Whited & Graham, 2021). For example, if the healthy group in the study was in better physical condition, with no previous use of cigarettes, and no seasonal allergies, they may have had a lower respiratory rate. Whereas, if the concussed group, had a higher incidence of sedentary behaviour, cigarette smoking, and seasonal allergies then they may have had a slightly higher RR as a group.

Snyder et al. (2021) did not find statistically significant RR differences between the PPCS group and the healthy control group. Based on the results of Siedlecki et al. (2018), Snyder et al. (2021), and the present study, the hypothesis that RR would be statistically significantly different in individuals with a concussive injury as compared to healthy controls is not supported in this cohort. Snyder et al. (2021) suggested that an alternate mechanism, such as tidal volume, could be associated with the difference in $ETCO_2$ values between the concussed and healthy individuals. Tidal volume can be described as the amount of air that moves in and out of the lungs during inspiration and expiration (Hallett & Ashurst, 2022). Tidal volume may be more likely associated with $ETCO_2$ because it more closely corresponds with the gaseous exchange of O_2 and CO_2 than RR (Hallett & Ashurst, 2022). Tidal volume plays a large role in the stability of O_2 and CO_2 levels in the lungs and blood (Hallett & Ashurst, 2022). As stated previously, $ETCO_2$

is the amount of CO_2 exhaled at the end of a breath. Therefore, it may be possible that the amount of O_2 and CO_2 that enters and exits the lungs (tidal volume) may have a more direct association with $ETCO_2$ values than the number of breaths/minute (RR).

Individuals who have experienced a concussion have been known to spontaneously start hyperventilating resulting in decreased alveolar and blood CO_2 levels (Go and Singh, 2013). Therefore, it is reasonable to assume that some individuals who have experienced a concussion may present with changes in their RR while completing a physical and a neurocognitive task. Siedlecki et al. (2018) and the present study used the NQ to ensure individuals who had a potential breathing disorder were excluded from the study to try to control for breathing disorders as a confounding variable. Therefore, individuals who may have had breathing dysfunction resulting from a concussive injury may have also been excluded from the study. Although these individuals may have been excluded, ultimately, it was more important to limit the participation of individuals who had a higher likelihood of a breathing disorder. Excluding these individuals gave the researcher more control over the variability in the results. Additionally, from an ethical and safety perspective, it was important to screen and exclude any individuals who may have been at risk of respiratory distress while completing a neurocognitive task and the walking tasks with a weighted vest.

Question 3. ***Was there a difference in executive functioning scores during the completion of the ImPACT® neurocognitive test between healthy versus concussed military members?***

The ImPACT® test was also used within this study to evaluate the difference between measures of executive functioning in concussed versus healthy individuals. Based on the results, when comparing the healthy military members to their concussed counterparts, there were no statistically significant differences in executive functioning scores across the different modules. Although there were no statistically significant differences, it should be noted that the healthy group had a slight trend favouring higher, on average scores, for verbal memory, visual memory, reaction time, and impulse control composites. This may mean that individuals who sustained a concussion in the present study may potentially have had a more difficult time with functions such as attentional processes, learning, and memory (Lovell, 2015). The small differences in scores for the ImPACT® test may reflect individuals' different strengths, weaknesses, and/or learning styles, however, they may also indicate the sections of the brain that were injured in the concussed group.

Military personnel are often and repeatedly exposed to acceleration, deceleration, rotational, and blast injuries throughout daily training and are exposed to harmful environments like war zones (Mullally, 2017). Due to the high variability of exposure, these individuals are at risk of brain injuries that could potentially affect any structure in the brain. Therefore, the difference in scores among multiple sections of the ImPACT® test may represent the different structures of the brain that are affected during an injury. Some structures of the brain that are responsible for executive functioning tasks highlighted by the ImPACT® test include the prefrontal cortex, the visual association area, and the premotor area (Tortora & Nielsen, 2014b).

The prefrontal cortex, housed in the frontal lobe, is the location for a human’s intellect, complex learning abilities, and recall of information. If this section of the brain were to be injured, they may become inattentive, rude, less creative, and unable to anticipate consequences (Tortora & Nielsen, 2014b). The visual association area, located in the occipital lobe, connects past and present visual stimuli and is extremely important in recognizing and processing what is being seen. If this section of the brain were to be injured, individuals could potentially have deficits in recognizing objects, faces, and making associations (Tortora & Nielsen, 2014b). An injury to the prefrontal cortex and visual association area may be associated with poor verbal memory and/or visual memory. The premotor area, located in the parietal lobe, is responsible for learned actions and complex activities serving as a memory for movements. If this region were to sustain an injury, an individual may have a difficult time with fine motor control or carrying out complex or skilled movements (Tortora & Nielsen, 2014b). An injury to the premotor area may be associated with poor reaction time and poor impulse control. The frontal, parietal, and occipital lobes are three of the largest sections of the brain, therefore, it makes sense that some of the scores in individuals who have sustained a concussion would be more likely to have deficits in these aspects of executive functioning. With more severe concussive impacts or where multidirectional forces are involved there may be multiple areas of the brain affected potentially impacting a variety of cognitive or functional capabilities for that individual.

Although no statistically significant differences were found in executive functioning scores between the concussed and healthy participants in the present study, the concussed group appeared to score lower reaction time values and higher visual motor speed scores than the healthy group. From a clinical perspective, this slight difference is important to consider because if reaction time was affected, although a complex process of sensory motor processing, it could be associated with an injury to the cerebellum. The cerebellum is located at the base of the brain posterior to the brainstem (Horwitz et al., 2000). The lack of breathing abnormalities/dysfunctions here may indicate that individuals in this group did not have an injury to this structure in the brain. Therefore, the absence of injury to the cerebellum may also indicate the absence of injury to the brainstem (that houses two key respiratory control centers) in the concussed sample for the present study. As for the visual motor speed composite scores, the behaviours are partially controlled by the frontal eye field that exists in the frontal lobe of the brain. The concussed group may have seemed to score better in the visual motor speed section possibly due to the variability of their injuries, or potentially due to the nature of their work. For example, the ability to effectively combine visual input with motor skills is a highly utilized skill within the military. Fast action is required in this population whether it is putting together a weapon, giving lifesaving medical care, or operating a heavy piece of machinery. This behaviour may be highly developed within this group of individuals that it may not be strongly affected by a concussive injury.

If a function like reaction-time was consistently higher in a concussed individual in the military, it could be putting lives at risk; the extra second could potentially be the difference between life and death. As previously discussed, there are many structures in the brain, of which tend to have over lapping responsibilities. Although, due to the severity of discrepancies, it may be more likely for an injury to occur to the cerebrum, there is a very real possibility that an injury could also occur to smaller structures like the cerebellum or the brainstem. Any injury to the brain can lead to severe consequences with altered cognitive functioning.

As previously mentioned, when possible, individuals will take the ImPACT® test when they are healthy, in order to establish a baseline for comparison if they were to sustain a concussion in the future (Lovell, 2015). The baseline test gives a clearer comparison to normative values and provides a stronger indication whether there is an injury, the severity of symptoms, and which areas of the brain and executive function may be affected (Lovell, 2015). For the purposes of this study, all participants completed the baseline test, ensuring there was no variability in data collection. Obtaining a baseline score to compare within-subjects ImPACT® scores may have provided a more accurate representation of each individual's executive functioning pre- and post-injury.

Although there were no statistically significant results between the ImPACT® scores it must be acknowledged that there was a statistically significant finding between the groups when examining PCSS scores that were completed within the ImPACT® test. Individuals belonging to the concussed group reported higher symptom scores than the individuals in the healthy control group. The PCSS is a 19-item self-report questionnaire embedded within the ImPACT®, that asked individuals to rate their current symptoms, of which are closely associated with concussive injuries. The lower the PCSS score, the better; a lower score represents a lower number and severity of symptoms as documented by the individual (Joyce et al., 2015). The highest possible score for the PCSS is 132 and the lowest possible score is 0 (Joyce et al., 2015). Therefore, the higher scores reported by the concussed group (M=22.92) may have indicated that the individuals in that group were experiencing a higher number and severity of PPCS as compared to the healthy group (M=12.05). The scores provided by the concussed group were still considered to be very mild. Similarly, the individuals recruited for this study have suffered a concussion and some individuals may have deficits for several weeks lasting up to one year or more (Permenter et al., 2022).

Limitations

Some limitations were identified pertaining to this study. First it is important to address the sample size recruited for this study (n=30), although power was obtained at a high value of

87.8%, a larger sample will always provide a more comprehensive representation of the population of interest and possibly impact on the findings and statistical results.

Another limitation is the variability of breathing patterns. Breathing is typically controlled via the ANS through an extensive collaboration of muscles and structures. The medullary and pontine respiratory groups signal the muscles in the neck and abdomen to perform inhalation and exhalation. Although the ANS sends continuous signals, breathing can be voluntarily controlled as well (Ikeda et al., 2017). Respiratory manipulation is often integrated during speech, singing, and breath holding tasks. Due to the high number of structures and functions involved during these actions, there are many internal (pulmonary and cerebral blood flow) and external factors (coughing, sneezing, weather, or allergies) that may influence breathing and alter the pattern (Patwa & Shah, 2015). To mitigate the effects of this limitation, the NQ was administered and utilized as a screening tool for disordered breathing patterns and the same clear instructions and verbal ques were provided to all participants to avoid participants breathing through their mouth and obtain consistent results. Individuals who may have had breathing dysfunction resulting from a concussive injury may have also been excluded from the study. In combination with the concussed individuals with mild symptoms who were cleared to return to work the screening of disordered or abnormal breathing pattern could have potentially excluded participants of interest.

The final limitation that should be noted is the variability of a concussive injury and the clinical presentation. Every individual heals from a concussion at different rates and the recovery of this injury can be changed/delayed via a variety of factors (Mccrory et al., 2017). Return to sport, work, and/or activity too early can increase the severity, number, and duration of symptoms, increase recovery time, and put individuals at risk of sustaining a second injury (Williamson & Goodman, 2006). Primarily, concussive injuries are difficult to diagnose, as they are often misunderstood and underreported. Since concussive injuries can be sustained in a variety of ways, it can also be difficult to identify what sections of the brain are specifically injured (Mullally, 2017). The mechanism of injury of a concussion can involve several different types of forces, which increases the potential number of locations a brain injury could occur and the metabolic and/or physiological functions that may be impacted (Mckee & Robinson, 2014). The subjectively reported symptoms that are experienced by the individual and the mechanism of injury may also provide insight on the location of the injury (Gardner & Yaffe, 2015). Due to the different structures/segments of the brain, a wide variety of symptoms may be associated with a concussive injury. Based on the variability and in the mechanism of injury and symptomatology of a concussion, it is important to keep in mind, for the purposes of this study, the type of concussion and location of injury for the participants may not correspond with an injury directly to the respiratory control centers in the brain. This limitation may have been a contributor to the lack of statistical significance in the present study as each participant in this study had their own unique concussive injury, symptoms, recovery, and timeline. This variability with concussive injuries makes it difficult to obtain a homogenous sample, therefore, it is likely to be a limitation for any study conducting research in a concussed population. Each of these limitations will hopefully be useful for future researchers to take into consideration when outlining the methodology for their studies.

Future Direction and Recommendations

There are currently very few studies that have explored the topic of concussion in the Canadian military, therefore, future researchers should expand on the epidemiology, etiology, clinical presentation, and treatment of concussive injuries in the CAF. Future researchers may consider using tools like the electroencephalogram (EEG) to monitor electrical brain activity pre-and post-deployment. Conducting an EEG on these individuals' pre-and post-deployment may provide a more comprehensive overview of the brain trauma that these individuals are encountering while overseas. Similarly, it may also be useful to monitor this population more closely with imaging technology such as computed tomography or magnetic resonance imaging scans to identify baseline results upon entering the military and to monitor if there are any neurological changes occurring longitudinally over the years or following deployment.

Additionally, research examining the effects of concussive injuries on breathing patterns should be furthered using the existing literature, methodology, and research designs. Future researchers should target individuals in the acute or sub-acute phase of a concussion. As mentioned previously, most adults recover from their first concussion within 7-15 days (Ellis et al., 2016; Tator, 2013). Therefore, most neurological changes and symptoms would be observed within the two-week time frame. This period may provide a more accurate representation of the potential short-term physiological changes in breathing function in individuals who have sustained a concussion. During a concussion, for the first 7-10 days the neurometabolic changes are occurring during a period in which there is also a 50% reduction in cerebral blood flow (Giza & Hovda, 2014). Treating a concussion typically incorporates a brief period of physical and cognitive rest, followed by a gradual increase in activity, along with consistent check-ins until medically cleared (May et al., 2020; Schneider, 2017). It may be valuable to monitor breathing measures at rest and during the completion of daily functional tasks for participants in this stage of a concussion. Participants for the present study were 2-12 months post-injury.

As stated previously, the number of concussive injuries is increasing, and as a result, concerns regarding the long-term effects are growing. Multiple post-mortem examinations of military veterans have already showed permanent neurological abnormalities consistent with diseases such as Alzheimer's disease and dementia in individuals who have suffered repeated brain injuries (Bieniek et al., 2015; Musumeci et al., 2019) Therefore, further examination of military veterans' brains longitudinally from the start of their career upon entering the military to obtain baseline values and post-mortem should be conducted to evaluate the level of trauma, neurometabolic, and/or chemistry changes over time.

A large number of individuals recruited for the present study were a part of CANSOFCOM (n=19). These individuals have an extremely high physical and neurocognitive demand in the work environment as well as high physical and mental/intellectual standards that must be met to qualify for CANSOFCOM. Therefore, future researchers conducting studies with populations in the CAF, may consider increasing the physical and neurocognitive workload for the participants. The majority of the sample found the procedures for the both the physical and neurocognitive task to place a very minimal amount of stress on the brain and body. Future researchers may consider increasing the walking speeds and/or increasing the weight of the vest. Researchers could also consider implementing a more challenging neurocognitive task or potentially adding some level of distraction to add to the cognitive stimulation/workload.

Chapter 6

Conclusion

The purpose of this study was to examine differences between healthy and concussed military members on measures of $ETCO_2$ and RR when completing a neurocognitive task (ImPACT®) and a physical task (walking on a treadmill with a weighted vest). This study also aimed to examine differences between healthy and concussed military members on executive functioning scores when completing a neurocognitive task (ImPACT®). Based on the neurometabolic and physiological changes that occur during a concussive injury, it is supported that the structures and functions of the brain could potentially be impacted. This is especially true when looking at a population that is often exposed to physically demanding and potentially life-threatening environments and repetitive sub-concussive impacts. Breathing abnormalities and dysfunctions can lead to poor gas exchange causing abnormally levels of O_2 and CO_2 in the blood and lungs (Patwa & Shah, 2015). The balance between O_2 and CO_2 are extremely important to each structure and organ in human body for survival and to effectively perform their required tasks (Patwa & Shah, 2015). Therefore, determining if respiratory abnormalities or dysfunctions are present in military members who have had a concussion within the past 2-12 months is important as it could affect their ability to perform daily living activities and advanced career related activities (i.e., physical activity, executive functioning tasks). The results of the present study, indicate that there were no statistically significant differences between healthy and concussed military members on executive functioning scores, RR, and $ETCO_2$ when completing physical and neurocognitive tasks. The results of this study did, however, show a slightly elevated RR and $ETCO_2$ values in the concussed group across both physical and neurocognitive tasks. Although the results of this study do not suggest concussive injuries influence breathing function in Canadian military members, it is important to continue this research. It is of great importance to increase the amount of literature on this topic within this population because each of the participants in this study have been exposed to repetitive sub-concussive injuries.

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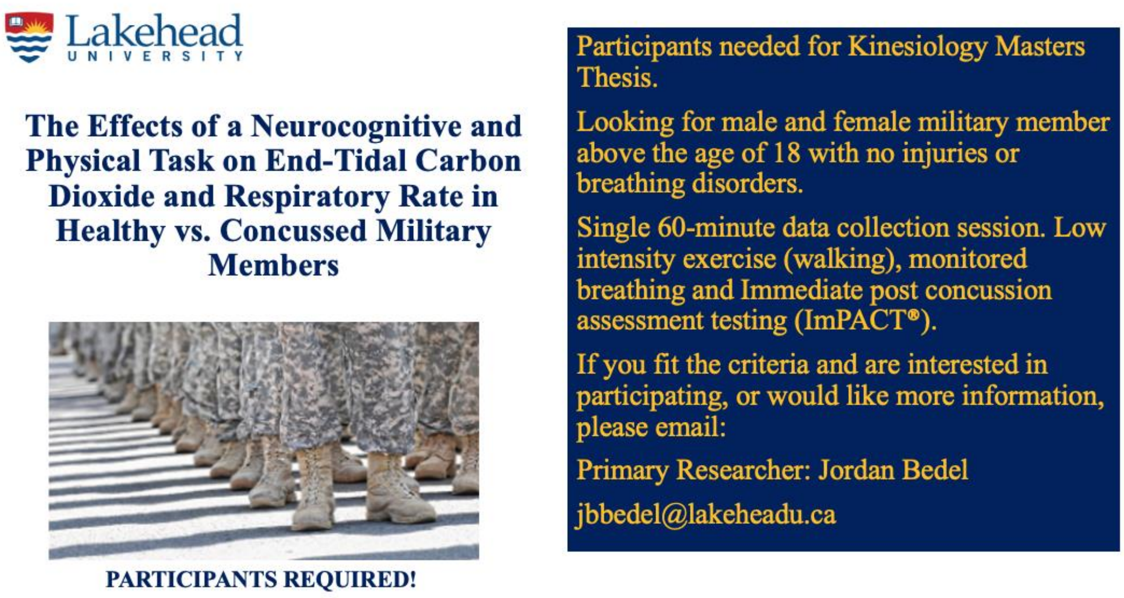
Appendix A

Recruitment Poster



Lakehead
UNIVERSITY

The Effects of a Neurocognitive and Physical Task on End-Tidal Carbon Dioxide and Respiratory Rate in Healthy vs. Concussed Military Members

PARTICIPANTS REQUIRED!

Participants needed for Kinesiology Masters Thesis.

Looking for male and female military member above the age of 18 with no injuries or breathing disorders.

Single 60-minute data collection session. Low intensity exercise (walking), monitored breathing and Immediate post concussion assessment testing (ImPACT®).

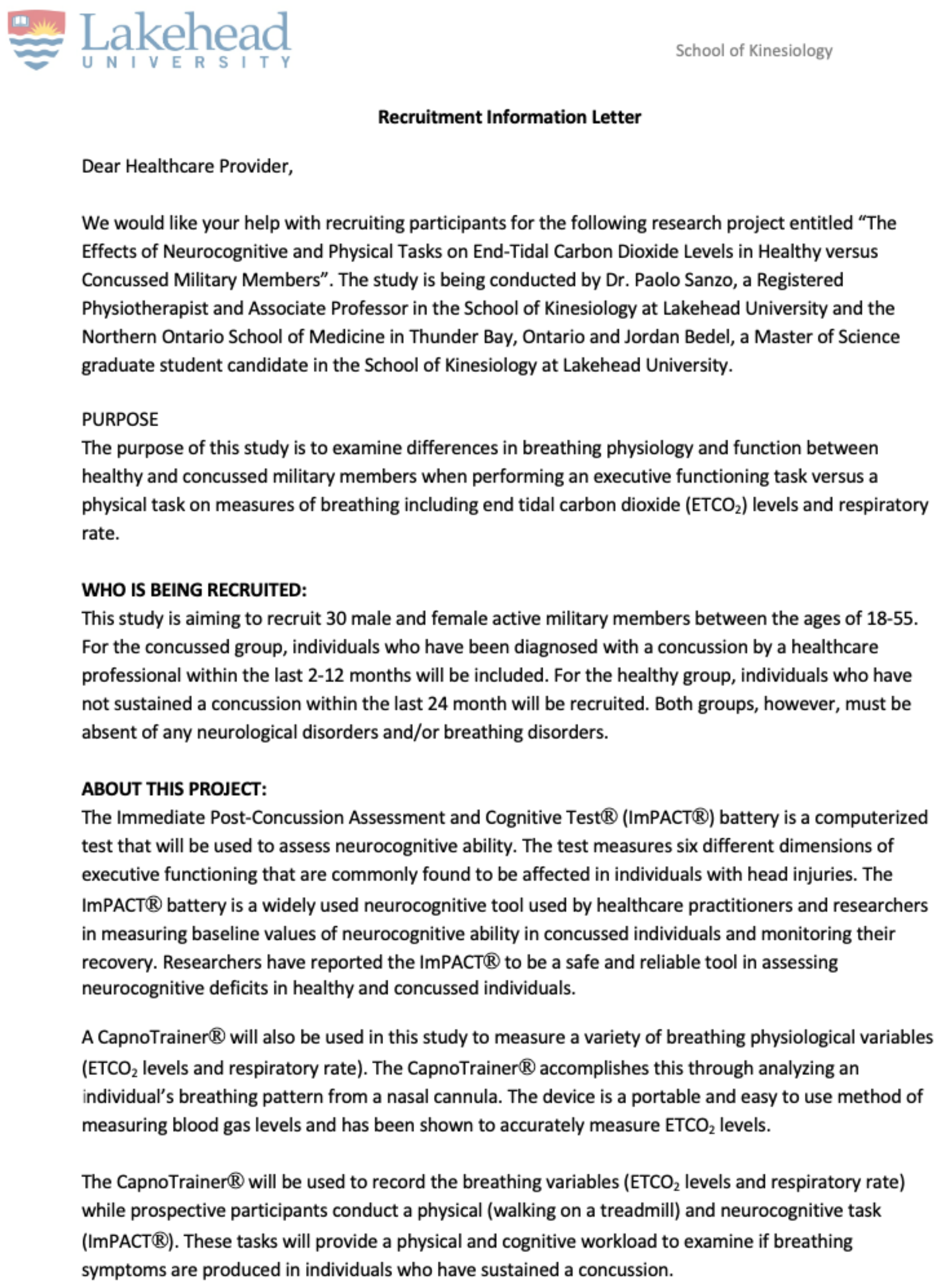
If you fit the criteria and are interested in participating, or would like more information, please email:

Primary Researcher: Jordan Bedel

jbbedel@lakeheadu.ca

Appendix B

Recruitment Information Letter



Lakehead
UNIVERSITY

School of Kinesiology

Recruitment Information Letter

Dear Healthcare Provider,

We would like your help with recruiting participants for the following research project entitled "The Effects of Neurocognitive and Physical Tasks on End-Tidal Carbon Dioxide Levels in Healthy versus Concussed Military Members". The study is being conducted by Dr. Paolo Sanzo, a Registered Physiotherapist and Associate Professor in the School of Kinesiology at Lakehead University and the Northern Ontario School of Medicine in Thunder Bay, Ontario and Jordan Bedel, a Master of Science graduate student candidate in the School of Kinesiology at Lakehead University.

PURPOSE

The purpose of this study is to examine differences in breathing physiology and function between healthy and concussed military members when performing an executive functioning task versus a physical task on measures of breathing including end tidal carbon dioxide ($ETCO_2$) levels and respiratory rate.

WHO IS BEING RECRUITED:

This study is aiming to recruit 30 male and female active military members between the ages of 18-55. For the concussed group, individuals who have been diagnosed with a concussion by a healthcare professional within the last 2-12 months will be included. For the healthy group, individuals who have not sustained a concussion within the last 24 month will be recruited. Both groups, however, must be absent of any neurological disorders and/or breathing disorders.

ABOUT THIS PROJECT:

The Immediate Post-Concussion Assessment and Cognitive Test® (ImPACT®) battery is a computerized test that will be used to assess neurocognitive ability. The test measures six different dimensions of executive functioning that are commonly found to be affected in individuals with head injuries. The ImPACT® battery is a widely used neurocognitive tool used by healthcare practitioners and researchers in measuring baseline values of neurocognitive ability in concussed individuals and monitoring their recovery. Researchers have reported the ImPACT® to be a safe and reliable tool in assessing neurocognitive deficits in healthy and concussed individuals.

A CapnoTrainer® will also be used in this study to measure a variety of breathing physiological variables ($ETCO_2$ levels and respiratory rate). The CapnoTrainer® accomplishes this through analyzing an individual's breathing pattern from a nasal cannula. The device is a portable and easy to use method of measuring blood gas levels and has been shown to accurately measure $ETCO_2$ levels.

The CapnoTrainer® will be used to record the breathing variables ($ETCO_2$ levels and respiratory rate) while prospective participants conduct a physical (walking on a treadmill) and neurocognitive task (ImPACT®). These tasks will provide a physical and cognitive workload to examine if breathing symptoms are produced in individuals who have sustained a concussion.

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RESEARCHER CONTACT INFORMATION:
If you have an individual in mind that meets the criteria of the study and also shows interest in participating in this study, please provide the person with Jordan Bedel's contact information. Jordan may be contacted either by telephone at (613)-601-6057 or by email at jbbedel@lakeheadu.ca. You may also contact the faculty researcher Dr. Paolo Sanzo by telephone at (807)-343-8647 or by email at psanzo@lakeheadu.ca.

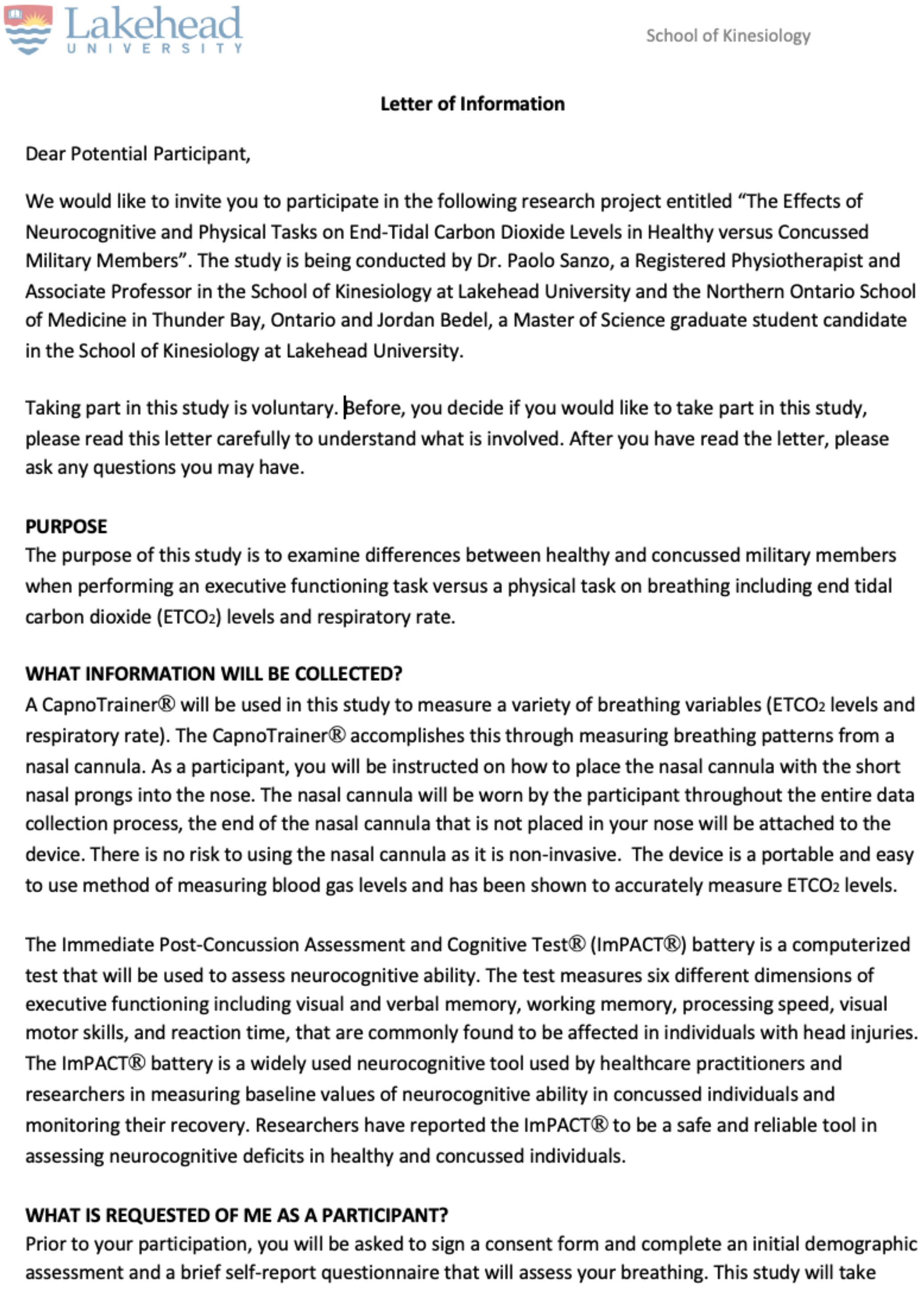
Sincerely,

Jordan Bedel, B.A. (Hons) Kin, Master of Science graduate student candidate, School of Kinesiology, Lakehead University, Thunder Bay, Ontario

Dr. Paolo Sanzo, DSc, MSc, BScPT, FCAMPT, CAFCI Associate Professor, School of Kinesiology at Lakehead University and Northern Ontario School of Medicine, Thunder Bay, Ontario

Appendix C

Participant Information Letter



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School of Kinesiology

Letter of Information

Dear Potential Participant,

We would like to invite you to participate in the following research project entitled "The Effects of Neurocognitive and Physical Tasks on End-Tidal Carbon Dioxide Levels in Healthy versus Concussed Military Members". The study is being conducted by Dr. Paolo Sanzo, a Registered Physiotherapist and Associate Professor in the School of Kinesiology at Lakehead University and the Northern Ontario School of Medicine in Thunder Bay, Ontario and Jordan Bedel, a Master of Science graduate student candidate in the School of Kinesiology at Lakehead University.

Taking part in this study is voluntary. Before, you decide if you would like to take part in this study, please read this letter carefully to understand what is involved. After you have read the letter, please ask any questions you may have.

PURPOSE

The purpose of this study is to examine differences between healthy and concussed military members when performing an executive functioning task versus a physical task on breathing including end tidal carbon dioxide ($ETCO_2$) levels and respiratory rate.

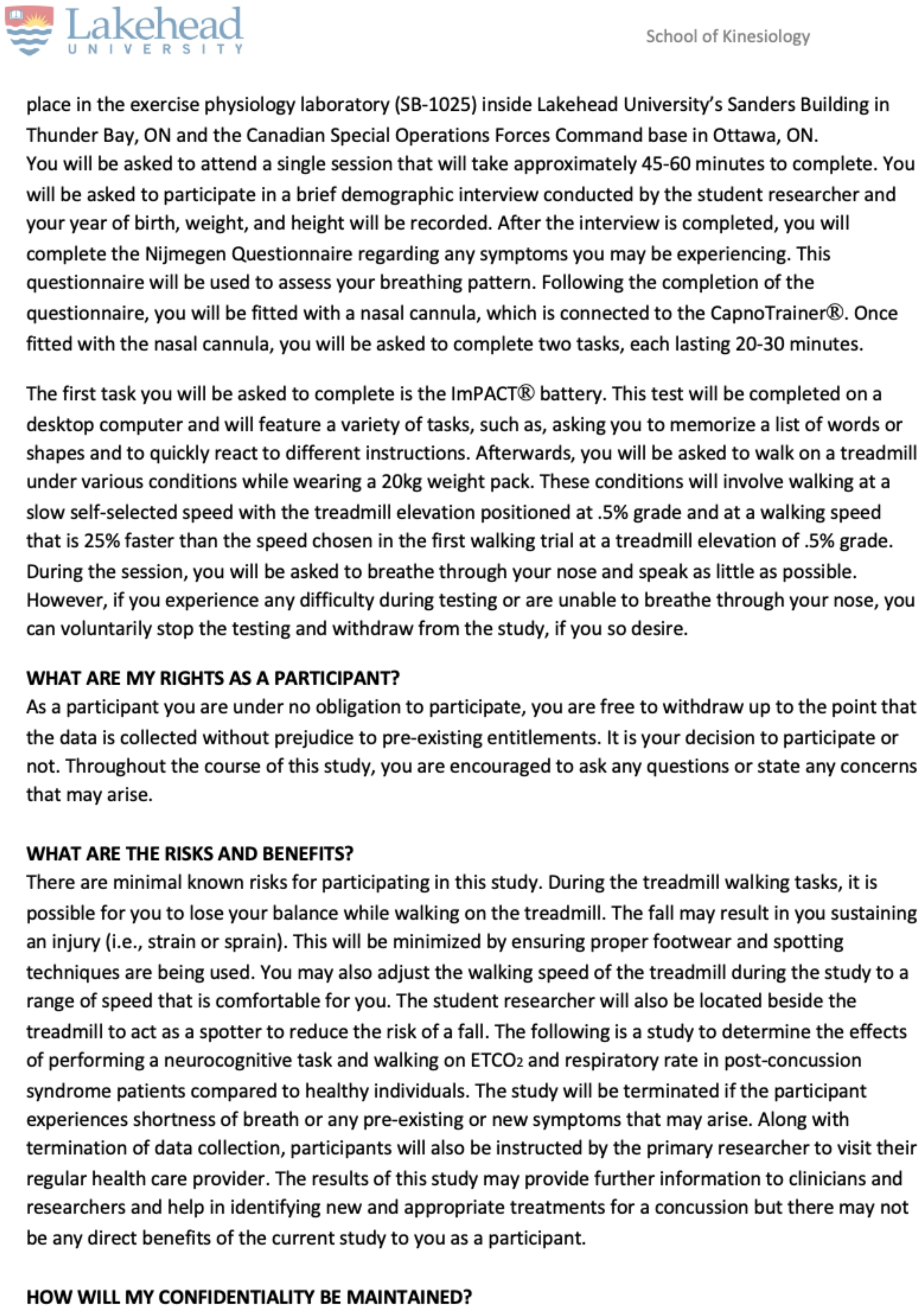
WHAT INFORMATION WILL BE COLLECTED?

A CapnoTrainer® will be used in this study to measure a variety of breathing variables ($ETCO_2$ levels and respiratory rate). The CapnoTrainer® accomplishes this through measuring breathing patterns from a nasal cannula. As a participant, you will be instructed on how to place the nasal cannula with the short nasal prongs into the nose. The nasal cannula will be worn by the participant throughout the entire data collection process, the end of the nasal cannula that is not placed in your nose will be attached to the device. There is no risk to using the nasal cannula as it is non-invasive. The device is a portable and easy to use method of measuring blood gas levels and has been shown to accurately measure $ETCO_2$ levels.

The Immediate Post-Concussion Assessment and Cognitive Test® (ImPACT®) battery is a computerized test that will be used to assess neurocognitive ability. The test measures six different dimensions of executive functioning including visual and verbal memory, working memory, processing speed, visual motor skills, and reaction time, that are commonly found to be affected in individuals with head injuries. The ImPACT® battery is a widely used neurocognitive tool used by healthcare practitioners and researchers in measuring baseline values of neurocognitive ability in concussed individuals and monitoring their recovery. Researchers have reported the ImPACT® to be a safe and reliable tool in assessing neurocognitive deficits in healthy and concussed individuals.

WHAT IS REQUESTED OF ME AS A PARTICIPANT?

Prior to your participation, you will be asked to sign a consent form and complete an initial demographic assessment and a brief self-report questionnaire that will assess your breathing. This study will take



place in the exercise physiology laboratory (SB-1025) inside Lakehead University's Sanders Building in Thunder Bay, ON and the Canadian Special Operations Forces Command base in Ottawa, ON.
You will be asked to attend a single session that will take approximately 45-60 minutes to complete. You will be asked to participate in a brief demographic interview conducted by the student researcher and your year of birth, weight, and height will be recorded. After the interview is completed, you will complete the Nijmegen Questionnaire regarding any symptoms you may be experiencing. This questionnaire will be used to assess your breathing pattern. Following the completion of the questionnaire, you will be fitted with a nasal cannula, which is connected to the CapnoTrainer®. Once fitted with the nasal cannula, you will be asked to complete two tasks, each lasting 20-30 minutes.

The first task you will be asked to complete is the ImPACT® battery. This test will be completed on a desktop computer and will feature a variety of tasks, such as, asking you to memorize a list of words or shapes and to quickly react to different instructions. Afterwards, you will be asked to walk on a treadmill under various conditions while wearing a 20kg weight pack. These conditions will involve walking at a slow self-selected speed with the treadmill elevation positioned at .5% grade and at a walking speed that is 25% faster than the speed chosen in the first walking trial at a treadmill elevation of .5% grade. During the session, you will be asked to breathe through your nose and speak as little as possible. However, if you experience any difficulty during testing or are unable to breathe through your nose, you can voluntarily stop the testing and withdraw from the study, if you so desire.

WHAT ARE MY RIGHTS AS A PARTICIPANT?
As a participant you are under no obligation to participate, you are free to withdraw up to the point that the data is collected without prejudice to pre-existing entitlements. It is your decision to participate or not. Throughout the course of this study, you are encouraged to ask any questions or state any concerns that may arise.

WHAT ARE THE RISKS AND BENEFITS?
There are minimal known risks for participating in this study. During the treadmill walking tasks, it is possible for you to lose your balance while walking on the treadmill. The fall may result in you sustaining an injury (i.e., strain or sprain). This will be minimized by ensuring proper footwear and spotting techniques are being used. You may also adjust the walking speed of the treadmill during the study to a range of speed that is comfortable for you. The student researcher will also be located beside the treadmill to act as a spotter to reduce the risk of a fall. The following is a study to determine the effects of performing a neurocognitive task and walking on $ETCO_2$ and respiratory rate in post-concussion syndrome patients compared to healthy individuals. The study will be terminated if the participant experiences shortness of breath or any pre-existing or new symptoms that may arise. Along with termination of data collection, participants will also be instructed by the primary researcher to visit their regular health care provider. The results of this study may provide further information to clinicians and researchers and help in identifying new and appropriate treatments for a concussion but there may not be any direct benefits of the current study to you as a participant.

HOW WILL MY CONFIDENTIALITY BE MAINTAINED?

All information that is provided and collected will be kept strictly confidential and you have the right to decline providing any personal information or answering any questions that you do not want to answer. You will be assigned a unique identification number to prevent identification from third parties and only the research team will have access to the recorded data and personal information. Full anonymity and confidentiality will be observed during the course of the research, in the final report, and in the presentation of the results. You will not be identified in any way as you will be provided with a unique identification number. If you are interested in obtaining your results, a copy will be provided upon completion of this study.

WHAT WILL MY DATA BE USED FOR?
The results from this study will be presented in a paper and oral presentation as part of the requirement of completing a thesis-based Master of Science graduate program. An abstract may also be submitted in the future to a scientific conference for consideration, with the possibility of a presentation.

WHERE WILL MY DATA BE STORED?
All of the information collected will be securely stored in Dr. Paolo Sanzo's office at Lakehead University for a period of five years. Any data or information that is sent electronically will also be password protected.

HOW CAN I RECEIVE A COPY OF THE RESEARCH RESULTS?
To receive a copy of the results of this study after completion, please provide an **email address** on the **consent form**.

WHAT IF I WANT TO WITHDRAW FROM THE STUDY?
Participation in this study is voluntary and you have the right to withdraw up to the point of data collection. If you would like to withdraw from this study prior to data collection, please contact Jordan Bedel by telephone at (613) 601-6057 or by email at jbbedel@lakeheadu.ca.

RESEARCHER CONTACT INFORMATION:
If you agree to participate in this study, please complete the attached consent form. If you have any other questions, please feel free to contact the primary researcher Jordan Bedel by telephone at (613) 601-6057 or by email at jbbedel@lakeheadu.ca or the faculty researcher Dr. Paolo Sanzo by telephone at (807)-343-8647 or by email at psanzo@lakeheadu.ca.

RESEARCH ETHICS BOARD REVIEW AND APPROVAL:
This research study has been reviewed and approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright at the Research Ethics Board at 807-343-8283 or research@lakeheadu.ca.

Lakehead UNIVERSITY School of Kinesiology

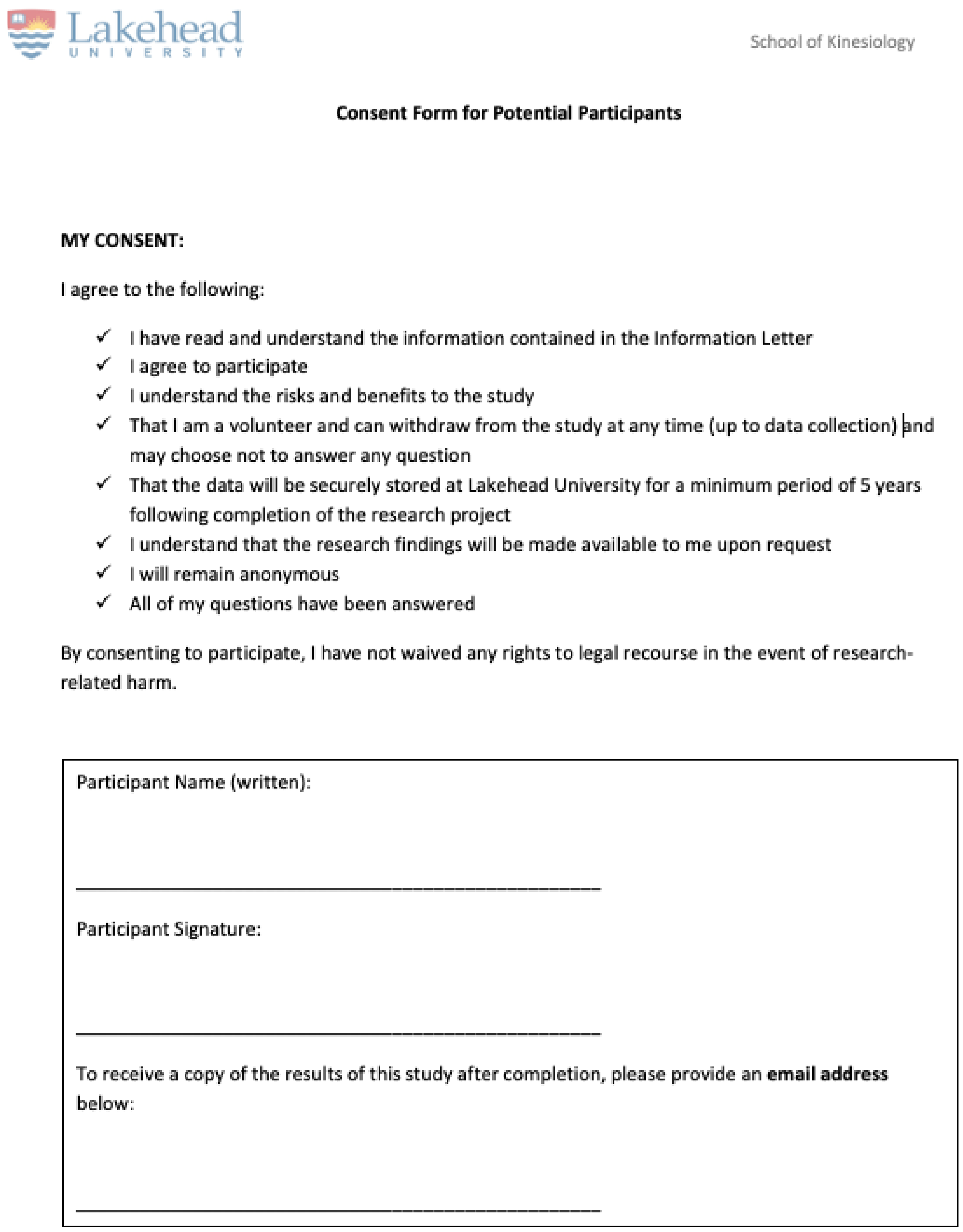
Sincerely,

Jordan Bedel, B.Sc. (Hons) Kin, MSc candidate Master of Science graduate student candidate, School of Kinesiology, Lakehead University, Thunder Bay, Ontario

Dr. Paolo Sanzo, DSc, MSc, BScPT, FCAMPT, CAFCI Associate Professor, School of Kinesiology at Lakehead University and Northern Ontario School of Medicine, Thunder Bay, Ontario

Appendix D

Consent Letter



Lakehead UNIVERSITY

School of Kinesiology

Consent Form for Potential Participants

MY CONSENT:

I agree to the following:

- ✓ I have read and understand the information contained in the Information Letter
- ✓ I agree to participate
- ✓ I understand the risks and benefits to the study
- ✓ That I am a volunteer and can withdraw from the study at any time (up to data collection) and may choose not to answer any question
- ✓ That the data will be securely stored at Lakehead University for a minimum period of 5 years following completion of the research project
- ✓ I understand that the research findings will be made available to me upon request
- ✓ I will remain anonymous
- ✓ All of my questions have been answered

By consenting to participate, I have not waived any rights to legal recourse in the event of research-related harm.

Participant Name (written):

____

Participant Signature:

____

To receive a copy of the results of this study after completion, please provide an **email address** below:

____

Appendix E

Nijmegen Questionnaire

Name:_________________________ Date:____________________

The Nijmegen Questionnaire

Please rate the score that best describes the frequency with which you experienced the symptoms listed.

Symptoms	Never	Rare	Some -times	Often	Very Often
Chest pain	0	1	2	3	4
Feeling tense	0	1	2	3	4
Blurred vision	0	1	2	3	4
Dizziness	0	1	2	3	4
Feeling confused	0	1	2	3	4
Fast or deep breathing	0	1	2	3	4
Shortness of breath	0	1	2	3	4
Tightness across chest	0	1	2	3	4
Bloated sensation in stomach	0	1	2	3	4
Tingling in fingers and hands	0	1	2	3	4
Difficulty breathing or taking deep breaths	0	1	2	3	4
Stiffness or cramps in fingers and hands	0	1	2	3	4
Tightness around the mouth	0	1	2	3	4
Cold hands or feet	0	1	2	3	4
Palpitations in the chest	0	1	2	3	4
Feelings of anxiety	0	1	2	3	4
Total					

Appendix F

Demographics Questionnaire

To be filled out by participant.

1. Year of Birth? ________________
2. Gender? ________________
3. Active military? Yes ________ No_________
4. Years in the military? _________
5. ____ Army ____ Navy ____Airforce
6. Division/Job Description _________________________________
7. History of concussion? Yes ________ No_________
8. If yes, number of previous concussions? ________________
9. When was your last concussion? ________________
10. How exactly did this injury happen?

    ____

    ____

11. History of respiratory disease/disorder? Yes ________ No_________
12. If "yes", what kind? ___________________________
13. History of neurological disorder? Yes ________ No_________
14. If "yes", what kind? ___________________________

To be collected by a member of the research team.

15. Identification number: _________________
16. Height? ___________________________ (cm)
17. Body Mass ___________________________ (kg)