The Effect of Concurrent Mental and Physical Fatigue on Physical Endurance Performance, Strength and Muscle Activity: A Pilot Study

by

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The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

Abstract

A significant amount of research focus has been dedicated to physical and mental fatigue individually, but their combined effects on physical performance are relatively underexplored. As such, the purpose of this pilot study was to evaluate the concurrent effects of mental and physical fatigue on upper limb neuromechanics and endurance performance, compared to just mental fatigue and physical fatigue elicited independently. Initial findings from this thesis provide initial support for concurrent mental and physical fatigue detrimentally affecting handgrip endurance and strength when compared to the mental fatigue and control conditions. As this pilot study was conducted to inform a larger planned data collection, several other areas for refinement in the protocol were identified, notably the addition of a familiarization session, utilizing only one post-measurement endurance trial, removing upper and lower ranges during the endurance trial, and adding the flexor carpi ulnaris muscle alongside the muscles used in this pilot study.

Keywords: Neuromuscular fatigue; Mental fatigue; Ergonomics; Force fluctuation; Endurance time

Author's Declaration

I hereby declare that this thesis consists of original work of which I have authored. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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____ **RAHUL K. PABLA**

Statement of Contributions

The work described in Chapters 1 to 4 was performed within the Occupational Neuromechanics and Ergonomics Laboratory at Ontario Tech University, using equipment and software designed by Dr. Nicholas La Delfa. Data collection was primarily conducted by myself with the help of Dr. Nicholas La Delfa. Under the regular advisement of Dr. La Delfa and Dr. Jeffrey Graham, I conducted all data synthesis, statistical analyses and primary interpretation of results. Dr. La Delfa and Dr. Graham provided feedback and made minor editorial adjustments to the manuscripts contained within.

I hereby certify that I am the sole author of this thesis. I have used standard referencing practices to acknowledge ideas, research techniques, or other materials that belong to others. Furthermore, I hereby certify that I am the sole source of the creative works and/or inventive knowledge described in this thesis.

Acknowledgements

I think it's safe to say this journey throughout my master's degree has been quite unconventional. I never would have imagined that this pandemic would hit and change my life and the lives of so many people around the world like it did. Nevertheless, I'm very grateful for all the knowledge, opportunities, and experiences I've gained throughout this degree and all the people I've met along the way.

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Table of Contents

List of Tables

Table of Figures

List of Abbreviations

ACC	Anterior Cingulate Cortex
ATP	Adenosine Triphosphate
CNS	Central Nervous System
ECR	Extensor Carpi Radialis
EEG	Electroencephalogram
EM	Experimental Manipulation
EMG	Electromyography
sEMG	Surface Electromyography
FCR	Flexor Carpi Radialis
FCU	Flexor Carpi Ulnaris
FS	Feeling Scale
GABA	Gamma-Aminobutyric Acid
IMI	Intrinsic Motivation Inventory
LMN	Lower Motor Neuron
MnPF	Mean Power Frequency
MVC	Maximum Voluntary Contraction
MVE	Maximum Voluntary Excitation
NMJ	Neuromuscular Junction
PFC	Prefrontal Cortex
PMF	Perceived Mental Fatigue
PNS	Peripheral Nervous System
PPE	Personal Protective Equipment
PPF	Perceived Physical Fatigue
RMS	Root Mean Square

RPE	Ratings of Perceived Exertion
TMS	Transcranial Magnetic Stimulation
TSE	Task Self-Efficacy
UMN	Upper Motor Neuron
VAS	Visual Analogue Scale

Chapter 1

1.0 - Thesis Introduction

Many individuals experience mental and/or muscle fatigue in their life, typically in school, work or even in day-to-day tasks such as driving. Mental fatigue is defined as a subjective feeling of tiredness or exhaustion that individuals will feel after being exposed to long or intense periods of cognitive activity (Marcora et al.,2009). This exhaustion can reduce motor performance and increase an individual's perception of their effort in a given task that can lead to earlier task failure (Marcora et al., 2009). Muscle fatigue is defined as a decrease in force generating capability in muscles and precipitates through central (i.e., neural) and peripheral (i.e., muscle fiber-level) processes (Enoka and Duchateau, 2008). Past research has focused on the individual effects of mental fatigue or muscle fatigue on motor performance and strength. However, few studies have examined the effects of combining both muscle and mental fatigue on physical tasks and their effect on subsequent performance (Mehta and Agnew, 2011), which is a common potential exposure in occupations such as surgery or dentistry, where prolonged static postures and high mental demand are required.

This thesis aims to answer the following central question: Does concurrent mental and physical fatigue have a greater impact on physical performance compared to mental and physical fatigue alone? As such, we hypothesize that mental fatigue and physical fatigue will have a negative impact on physical performance separately, and the combination of mental and physical muscle fatigue will yield greater detrimental results on physical performance as compared to mental and muscle fatigue independently.

This study consisted of four experimental conditions conducted on separate days in a repeated measures design. The neuromuscular fatigue condition required participants to squeeze the handgrip transducer at 15.3% maximum voluntary contraction (MVC) for 15 seconds followed by 15 seconds of rest for a total of 15 minutes. This exposure level (i.e., 15.3% MVC at a duty cycle of 50%) is what would be considered the ergonomic upper limit for this type of repetitive work and was expected to elicit an initial fatigue response in the form of decreased MVC and endurance times. The mental fatigue condition required participants to complete an arithmetic test for a total of 15 minutes and was also expected to result in small decreases in MVCs and endurance times, based on prior research. The concurrent condition required participants to complete both the arithmetic test and squeeze the handgrip transducer at 15.3% MVC for 15 seconds intermittently for 15 minutes and was expected to result in significant decreases in MVCs and endurance times. Finally, the control condition required participants to watch an emotionally neutral documentary for 15 minutes. It was hypothesized that both physical and mental fatigue would have similar negative impacts on physical performance (reduced endurance time, reduced grip strength and mean power frequency, increased EMG amplitude, increased force fluctuations and absolute error), and the combination of mental and physical fatigue will yield greater detrimental results on these performance metrics as compared to mental and muscle fatigue independently.

It is important to note that the study presented within this thesis represents initial pilot data. Due to the restrictions resulting from the COVID-19 pandemic, I was not able to collect data for a full study, but four participants were collected to initially evaluate this study’s protocol and to make recommendations and adjustments for a larger-scale study. Therefore, the results presented in this thesis can only be interpreted as initial trends, but these trends still provide valuable insight towards the novel protocol proposed in this thesis. This thesis presents a substantial narrative literature review focusing on the origins of mental and physical fatigue and their known effects on subsequent task performance (Chapter 2). This will be followed by a description of the pilot study that was undertaken (Chapter 3). The thesis will conclude with a final section summarizing the important findings and suggesting modifications for a large-scale version of this research (Chapter 4).

Chapter 2

2.0 - Introduction to Literature Review

Many occupations involve tasks that require workers to use the strength and coordination of their upper limbs to safely and efficiently complete their duties. In the modern age, muscle fatigue and pain are becoming more prominent and contribute to musculoskeletal disorders and increased risk of injuries (Mehta & Agnew, 2011). In addition to this, most jobs include some mental strain on its workers. This can range from stress, extended periods of focus, or even thinking in academia that will eventually bring about mental fatigue. Impairment in motor function due to mental fatigue can affect their ability to do their jobs safely and effectively which increases the risk of musculoskeletal injury (Lundberg et al., 2002). Mental fatigue can be described as a psychophysiological state that is caused by extended or intense periods of cognitive activity that results in feelings of tiredness or lack of energy (Boksem & Tops, 2008). Alternatively, muscle fatigue can be described as a decrease in the maximal force output that activated muscles are able to produce (Enoka & Duchateau, 2008). The effects of muscle fatigue and mental fatigue have been extensively researched individually; however, there is limited research on the interacting effect of both exposures on the performance on upcoming tasks.

The aim of this thesis is to assess the combined effect of mental and neuromuscular fatigue on strength and other indicators of upper limb performance. As such, this chapter will review the existing literature pertaining to mental and neuromuscular fatigue to help contextualize this research.

2.1 - Neuromuscular Fatigue

2.1.1 Introduction

Neuromuscular fatigue is often defined as a diminished capacity to produce force after completion of an exercise-induced task that is caused by changes in the central nervous system (CNS) and peripheral nervous system (PNS) (Enoka and Duchateau, 2008; Gandevia, 2001). Neuromuscular fatigue relates to motor unit activation and how their activation changes over the course of a fatiguing task. A motor unit consists of a motor neuron and the specific muscle fibers that it innervates (Duchateau & Enoka, 2011). The actions of motor units allow for muscle action and each muscle fiber generally receives input from one neuron; however, a single motor neuron may innervate many muscle fibers (Henneman, 1957). Motor units are recruited or de-recruited on the basis of motor neuron size and essentially control the amount of muscle tissue being activated. This means that motor units are activated or inhibited based on the intensity of work that the muscles are required to output. During fatigue, the firing of motor units slows down and will contribute to the loss of force production (Henneman, 1957). The production of skeletal muscle force depends on contractile mechanisms and the failure of various factors can contribute to the development of muscle fatigue which includes vascular and metabolic factors (Wan et al., 2017). This decrease in skeletal muscle force can be clearly seen in the comparison between baseline and post-fatigue maximum voluntary contraction (MVC) values.

Neuromuscular fatigue can be measured and quantified using several experimental methodologies. The primary modality, or 'gold standard' is to evaluate the decline in muscle strength over time via MVC. Another approach that provides a surrogate measure for neuromuscular fatigue is through the analysis of electromyographic (EMG) signals. Surface EMG signals are commonly used in research due to their accessibility and non-invasive nature and can be used to interpret muscle fatigue as an increase in amplitude (during sub-maximal fatiguing task) and a decrease in spectral frequencies (Enoka & Duchateau, 2008). EMG amplitude reflects the level of motor unit activation since an increase in motor unit recruitment and firing rate will occur to maintain force output in sub-maximal fatiguing conditions. This increase in neural drive is reflected as an increase in EMG amplitude, which generally scales with the level of neuromuscular fatigue (Enoka & Duchateau, 2008). It is also important to note that neuromuscular fatigue is variable between participants. This means that some participants may have a shorter or longer time to fatigue value depending on various factors such as: their ability to recruit motor units, muscle endurance, vascularity, and more.

Furthermore, force fluctuations are another metric that can be used to assess neuromuscular fatigue. Force fluctuations refer to the variability of the output force normalized to the mean output, otherwise referred to as the coefficient of variation (Enoka et al., 2003). A study by Shortz and Mehta (2017) found that as endurance time decreased, force fluctuations in the flexor carpi radialis (FCR) and extensor carpi radialis (ECR) increased during their concurrent mental and neuromuscular fatigue condition. An increased amount of force fluctuation indicates that there are more error corrections in the targeted muscles which occurs because the muscles are exhausted and have a reduced ability to smoothly generate enough force to stay at the targeted exertion level (Lin et al., 2014; Dipietro et al., 2009). The force generated by a muscle results in various force amplitudes (as seen in EMG) that depend on the contractile and discharge attributes of the firing motor units (Enoka et al., 2003; Christakos, 1982). It is difficult to determine which mechanisms cause force fluctuations in muscles, however, computer simulations and studies conducted on a simple motor system both suggest that the maximum force capacity of the muscle and the patterns that the motor units fire in (such as motor unit discharge synchronization) contribute to force fluctuations (Enoka et al., 2003; Yao et al., 2000; Keen et al., 1994). As a muscle progresses closer to fatigue, larger motor units innervate many powerful muscle fibers which contribute to increased force fluctuations when compared to smaller motor units that innervate a small number of muscle fibers for fine control (Purves et al., 2001; Henneman, 1957; Enoka et al., 2003).

The physical manifestations of muscle fatigue are typically attributed to both central and peripheral mechanisms within the neuromuscular system. Central fatigue is associated with changes in the central nervous systems (e.g., brain and spinal cord) that affect performance, whereas peripheral fatigue is associated with localized changes in muscle fibers that affect performance (Gandevia, 2001; Kent-Braun, 1999). Both central and peripheral factors contribute to muscle strength and endurance. Measures of central fatigue are difficult to measure without incorporation of neurophysiological techniques such as transcranial magnetic stimulation (TMS) or twitch interpolation. However, measures more specifically attributed to peripheral fatigue, via measurement of MVC and surface EMG, will be tracked in this thesis study as cursory indicators of neuromuscular performance.

2.1.2 Central Fatigue

Central fatigue involves events occurring in the brain, spinal cord and motor neurons prior to reaching the neuromuscular junction (Gandevia, 2001). Central fatigue involves the neural systems that provide input to the muscle fibers; this includes the motor cortex and the neural pathways that descend the spinal cord to innervate motor neurons (Ashley-Ross, 2005). The central contribution to neuromuscular fatigue has been characterized by decreases in voluntary activation in both maximal and submaximal exertion tasks. Although many studies have explored the effects of central fatigue on various factors such as grip strength and MVCs, the exact cause of central fatigue is still unknown. Central fatigue is a complex phenomenon and there are multiple factors that may limit exercise performance (Meeusen et al., 2006). There are many different chemicals in the brain used for signal transmission, but glutamate, acetylcholine, adenosine and GABA have all been seen to be involved with central fatigue (Meeusen et al., 2006). Furthermore, it is likely that the combined interactions of various factors such as cerebral metabolic, thermodynamic and hormonal responses during exercise contribute to the decrease in communication between the brain and the peripheral muscles (Meeusen et al., 2006).

The CNS produces various excitatory and inhibitory inputs on the spinal motor neurons via neurotransmitters such as glutamate and GABA, which ultimately activate motor units (MUs) to achieve the force output (Wan et al., 2017). Exercise, such as the neuromuscular fatigue protocol (inducing handgrip fatigue alone) utilized in this thesis, likely causes changes in the CNS's neurotransmitter concentrations which may be a contributing factor in central fatigue. Submaximal fatiguing tasks can induce central fatigue as more motor units are recruited and firing rates are increased to continue the fatiguing task until maximum effort is reached. From this point, changes in summation of motor unit action potentials and a reduction in neural drive after task failure may contribute to the development of central fatigue (Taylor and Gandevia, 2008). The induced handgrip fatigue may have negative carryover effects on upcoming tasks by causing central fatigue in addition to peripheral fatigue to our target muscles to decrease force production when fatiguing the forearm muscles (Kennedy et al., 2013).

Additionally, strenuous cognitive tasks have also been found to induce central fatigue (Bray et al., 2008). When central fatigue develops, the signal transmission from the brain to the muscle becomes impaired which affects the muscle’s ability to maintain optimal muscle contraction, possibly due to changes in neurotransmitter concentrations, hormonal responses during exercise, and an impaired ability to designate resources to complete tasks (Meeusen et al., 2006; Wan et al., 2017; Kennedy et al., 2013; Alder et al., 2020) which contributes to the decreased grip MVC values in participants. A study by Mehta and Parasuraman (2014) found that interference in the prefrontal cortex (PFC) may influence motor output during concurrent physical and cognitive tasks. The study reported that EMG Root Mean Square (RMS) of the flexor carpi radialis (FCR) and extensor carpi radialis (ECR) increased over time for both the neuromuscular fatigue and concurrent fatigue conditions (Mehta & Parasuraman, 2014). Furthermore, activation of the PFC has been posited as an indicator of central fatigue as it is involved with the pre-motor areas and plays a role in movement planning and decision making (Thomas & Stephane, 2008). Mental fatigue has been seen to increase activation of the PFC which has been linked to increased cerebral perfusion caused by a buildup of by-products produced during exercise and increased somatomotor activation in the brain. This increase in blood flow to the PFC may be due to additional neural activation that is needed to generate efferent motor commands which could be a contributing factor on why central fatigue can affect physical performance (Mehta and Parasuraman, 2014; Nobrega et al., 2014). Previous research has found that the manifestation of central fatigue is task specific, with continuous low-intensity exercise more often inducing greater central fatigue (Kennedy et al., 2013; Place et al., 2009). Both maximal and sub-maximal voluntary contractions are capable of producing central and peripheral changes; however, central fatigue is more often associated with low-intensity continuous exercise while high-intensity maximal exercise is more often associated with peripheral fatigue (Kennedy et al., 2013).

Furthermore, completing hand gripping tasks have been shown to induce central fatigue and even affecting performance in parts of the body unrelated to the gripping task performed. Kennedy at al. (2013) concluded that handgrip fatigue induces central fatigue that decreases force production in distal and unrelated ankle plantar-flexor muscles (Kennedy et al., 2013). In this research study, participants completed a bi-lateral handgrip fatiguing protocol (maximal or submaximal) with pre-post comparisons of ankle MVCs and handgrip MVCs. The results indicated that the handgrip fatiguing protocol decreased handgrip and ankle MVCs and decreased voluntary muscle activation of the non-fatigued ankle plantar-flexor muscles (Kennedy et al., 2013). In addition to this, both the maximal and submaximal handgrip fatigue protocols showed similar decreases in strength, but the maximal protocol recovered faster over the 1, 2, 5, 7, and 10-minute recovery period. The decrease in handgrip MVCs is caused by both central and peripheral fatigue as the muscles were fatigued due to the fatiguing protocol and the decrease in ankle MVCs are solely caused by central fatigue as the ankle plantar-flexor muscles were not fatigued (Kennedy et al., 2013).

To summarize, central fatigue involves events that are occurring in the CNS and decreases voluntary muscle activation in physical tasks. Although the exact mechanisms of central fatigue are not well-understood, literature suggests that it can be due to changes in neurotransmitter concentrations, hormonal responses during exercise, and an impaired ability to designate resources to complete tasks (Meeusen et al., 2006; Wan et al., 2017; Kennedy et al., 2013; Alder et al., 2020).

2.1.3 Peripheral Fatigue

Peripheral aspects of fatigue describe events that originate outside the central nervous system, specifically events that occur distal to the motor neurons and within the muscle fibers. Neuromuscular fatigue can occur after repetitive or prolonged muscle contractions, resulting in insufficient blood flow to the muscle and a buildup of metabolites which contribute to the decrease in physical performance (Sjogaard et al., 1986). For instance, this is apparent in a study by Merton (1954) which concludes that even when peripheral fatigue developed, if the blood supply was cut off with a blood pressure cuff, then twitch force did not recover, and participants were not able to exert MVCs to their full potential. With this, Merton (1954) states that voluntary strength could not recover until peripheral blood flow returns to the muscles, which indicates that fatigue is not only the result of the central nervous system but of peripheral factors as well. Other peripheral factors of fatigue include inhibitory responses to metabolite accumulations, such as hydrogen ions and inorganic phosphates (Pi), which slow the excitation process that initiates at the neuromuscular junction (Kent-Braun, 1999). The neural signal may fail to be transmitted to the muscle, or alternatively, the muscle may lose sensitivity to a neural signal. These have been observed in both high and low intensity exertion and cause a decline in muscle force output (Kent-Braun, 1999). A contributing factor to the failure of neuromuscular transmission is the depletion of neurotransmitters released in the synapse and this may occur because the available vesicles decline, as well as lowered vesicle content of the neurotransmitter (Wu & Betz, 1998). Post-synaptic potential failure (synaptic depression) may also occur even though there is a neural signal and sufficient acetylcholine, and calcium is available. This is due to a desensitization of neurotransmitter receptors during prolonged exposure to neurotransmitters, therefore even if there is enough ACh to bind to receptors, or enough calcium to bind to the tropomyosin complex, they will be unable to do so.

To summarize, peripheral fatigue involves events occurring beyond the CNS and can directly result in decreases in muscle strength, endurance, and is observed through increases in EMG amplitude. Literature suggests that it may be caused by inhibitory responses to metabolite accumulation, the neural signal failing to transmit, the muscle failing to respond to the signal and the depletion of neurotransmitters in the neuromuscular junction (NMJ) (Kent-Braun, 1999; Wu & Betz, 1998). Our current study induces peripheral fatigue by asking participants to perform a 15-minute intermittent handgrip endurance protocol with and without a mentally fatiguing task.

2.2 - Neuroanatomy

The neuroanatomical components primarily involved in this study will first be discussed from the origin of the signal to the movement of the muscles. For a participant to move their limbs, a signal must first be generated and sent from the brain, which is the origin of the descending tract. This begins in the frontal lobe of the brain which is responsible for many functions such as speech, language, and memory, but it is also responsible for motor control. Furthermore, signals will also need to be sent back up to the brain via the ascending tract. This starts at proprioceptors that give feedback to a participant’s brain on where their hand is located in space, force output, and adjustment of force output. These tracts work in conjunction with motor units located in muscles, the neuromuscular junction, and the sliding filament model.

2.2.1 Descending Tract

Output from the descending tract deliver signals from the brain to the target muscle. The signal will start in the premotor cortex which will prepare for voluntary movement. It will then send action potentials to the primary motor cortex which is essential for the execution of voluntary movement (Javed & Lui, 2018). From the primary motor cortex, the signal will travel down the spinal cord which consists of upper motor neurons (UMN), interneurons and lower motor neurons (LMN).

The UMN tract delivers signals to spinal interneurons and lower motor neurons exiting the spinal cord. Most UMNs will synapse with interneurons before they synapse with LMN, but there are some tracts that consist of direct UMN to LMN pathways (Javed & Lui, 2018). UMNs are essential for the initiation of voluntary movement in humans and are located within the cerebral cortex and in the brainstem. There are three types of UMNs: medial, lateral, and anterior nonspecific; however, lateral UMNs are the most relevant to this study. Lateral UMNs are used for fine control of the muscles in our body and face, which means they will be used when participants exert grip MVCs. LMNs transmit signals directly to skeletal muscles which result in the contraction of muscle fibers that allow for the movement of our limbs (Mendoza and Foundas, 2007). LMNs are the only neurons that convey signals to the extrafusal and intrafusal skeletal muscle fibers and are subject to the excitatory and inhibitory input from upper motor neurons. There are two main types of LMNs, alpha and gamma. Alpha motor neurons are associated with large, myelinated axons which make up motor units. A motor unit consists of a motor neuron and the specific muscle fibers that it innervates (Duchateau & Enoka, 2011). Motor units allow for muscle action and each muscle fiber generally receives input from one neuron, however a single motor neuron may innervate many muscle fibers. The axons in a motor unit project to the extrafusal skeletal muscles which are the major force generating structures (Jacobson, 2011). Gamma motor neurons consist of medium-sized myelinated axons and project to the intrafusal fibers in the muscle spindle that are responsible for sensory and stretch functions (Jacobson, 2011).

There are two relevant main descending pathways that are responsible for delivering signals to the muscles, these include the lateral corticospinal tract and the rubrospinal tract. The lateral corticospinal tract crosses over to the contralateral side in the medulla and runs down the entire length of the spinal cord. It is the primary pathway for motor information in the body and is responsible for controlling movement of both the upper and lower contralateral limbs (Javed & Lui, 2018). The rubrospinal tract originates from the red nucleus in the midbrain, crosses over in the midbrain to the contralateral side and descends down the spinal cord and terminates in the cervical region. The tract is responsible for the movement of larger muscles, and it primarily facilitates flexor muscles of the upper limbs (Jacobson, 2011). Since participants will be using their dominant hand to complete handgrip MVCs, the lateral corticospinal tract is essential since it controls the upper limbs. In addition to this, the rubrospinal tract is also needed as the forearm muscles used in this study fall under the jurisdiction of the tract.

2.2.2 Ascending Tract

The main ascending pathway responsible for delivering signals from the muscles back up to the brain is the dorsal column medial lemniscus pathway. The dorsal column has some function in proprioception but is mostly used for fine touch and vibration (Al-Chaer, 1996). The proprioception signals come from proprioceptors in the muscles and the fibers from those receptors then go to the dorsal root ganglion. The signal then travels up the spinal cord from the fasciculus cuneatus and to the medulla where it crosses over and travels up the medial lemniscus. Finally, the signal will travel to the thalamus where it will go to the somatosensory cortex (Anderson, 2011). This tract is relevant to this thesis as participants will need to have conscious awareness of their limb position and the handgrip transducer, how much force they are exerting, and how much to adjust their force output to stay within the force range defined by the task. Participants will also be required to adjust their force output based on real-time force feedback on a screen. As such, the optic tract will be used and is responsible for delivering signals from the retina to the occipital lobe to process information (Mehra and Moshirfar, 2021). The pathway carries electrochemical signals produced by the retina which then carries neural signals to the optic nerve, optic chiasm, lateral geniculate bodies and finally the visual cortex in the occipital lobe (Mehra and Moshirfar, 2021). This tract is relevant to this thesis as participants will adjust how much force they are exerting in order to match our specified MVC value displayed on a screen based on real-time force feedback.

2.2.3 Motor Units

The force that a muscle can exert will depend on the number of motor units that are recruited within the muscle fiber and the rate at which the action potentials are discharged from the motor neurons (Enoka, 2012). A motor unit consists of a LMN in the ventral horn of the spinal cord, its axon and the specific muscle fibers that it innervates (Duchateau & Enoka, 2011). The individual and combined actions of motor units produce muscle action, and each muscle fiber generally receives input from one neuron, however a single motor neuron may innervate many muscle fibers. Motor units vary in size, with smaller motor units innervating few, slow-contracting muscle fibers to generate small forces, and large motor units innervating more muscle fibers to generate larger, more powerful forces (Purves et al., 2001). Motor units also differ due to the type of muscle fibers that they innervate. Smaller motor units are called slow-twitch motor units and are used for activities that require continuous muscle contraction. Larger motor units are called fast fatigable motor units and as the name suggests, they are quick to fatigue but are able to generate more force within a short period of time. Finally, there are fast fatigue-resistant motor units that are an intermediate size and are able to generate twice the force of slow motor units but are more resistant to fatigue (Purves et al., 2001).

Muscle contractions emerge from the activation of motor neuron pools from synaptic inputs that come from descending tracts, interneurons, and peripheral afferent feedback (Enoka, 2012). When performing a muscle contraction, the signal sent from the spinal cord to the muscle consists of multiple action potentials from the motor units that were recruited to complete the contraction. During sustained or repetitive contractions, electromyography (EMG) has been used to measure some summation of motor unit activity by recording the action potentials generated by the motor units as they propagate down the muscle membrane. During submaximal contractions, an increase in EMG amplitude is observed after the completion of a long-duration contraction since more motor units are progressively recruited to make up for muscle fatigue (Enoka, 2012; Dideriksen et al., 2011). As fatigue progresses during a task, the motor neurons receive less excitatory inputs caused by an increased feedback transmission by chemically sensitive type III and IV afferents and reduced feedback in stretch sensitive afferents (Dideriksen et al., 2011).

Surface electromyography (sEMG) was used to assess the activity of the underlying muscles in this pilot study. Surface electromyography is non-invasive, as electrodes are placed directly on the skin overlying the muscle of interest. The electrodes are able to measure the electrical activity of the muscles through the skin, but this method is susceptible to signal impedance from surrounding tissue. These electrodes record the summated electrical activity of motor units in the muscle fibers (Backus et al., 2011). Surface electromyography was used in the study to assess muscle activity of the extensor carpi radialis (ECR) and flexor carpi radialis (FCR) of the dominant arm during the handgrip MVCs and endurance trials. The amplitude and power spectrums measured from the sEMG were used to assess the degree of muscle activation and fatigue. sEMG can be used to assess the amount of fatigue through the Henneman's size principle which states that gradual recruitment of larger motor units allows for a controlled motor output (Henneman, 1957). This motor recruitment is what causes an increase in amplitude in EMG recordings during neuromuscular fatigue (Enoka & Duchateau, 2008).

2.2.4 Henneman's Size Principle

The Henneman's size principle is defined as the orderly recruitment of specific motor units to produce smooth muscle actions (Henneman, 1957). This principle allows the CNS to fine tune skeletal muscle activity to meet demands of the task being performed. Within a single motor pool, the motor neurons are generally recruited in order of ascending size and as muscle force requirements increase, motor neurons will be recruited with progressively larger axons. This serves two purposes: 1) To minimize the development of fatigue by using the most fatigue resistant fibers more often and 2) to allow for equally fine control of force at all levels of force output (Henneman, 1957).

2.2.5 Neuromuscular Junction

Once the signal has reached the end of the LMN, it will have to cross the neuromuscular junction (NMJ). The action potential from the LMN will open up voltage-gated calcium channels that allows for the movement of vesicles in the axon that release acetylcholine (ACh) into the synaptic cleft. Once ACh binds to its receptor on the muscle fiber, the ligand-gated Na^+/K^+ channels will produce an end plate potential that will allow for an influx of sodium ions into the sarcolemma, causing an action potential in the muscle fiber. This process will be in constant use during the physical fatiguing condition in this thesis. As mentioned above, one possible cause of fatigue may be the depletion of neurotransmitters released in the synapse due to the decline of available vesicles, as well as lowered vesicle content of the neurotransmitter (Wu & Betz, 1998). This would lead to the onset of fatigue, impairing muscle strength and endurance.

2.2.6 Sliding Filament Model

Furthermore, the action potential that travels through the muscle fiber will commence the contraction of the muscle. This process is known as the sliding filament model, and it proposes that a muscle shortens or lengthens by the actin and myosin filaments sliding past each other without changing length. The way this works is the myosin cross-bridges cyclically attach, rotate, and detach from actin filaments by using Adenosine Triphosphate (ATP). This causes a change in sarcomere size with force being produced at the Z bands. A more in-depth explanation is that the action potential created by the end plate potential causes calcium to be released from the sarcoplasmic reticulum. The calcium then binds to the tropomyosin complex on the actin filaments which causes a structural change to expose the myosin binding sites. The myosin heads are then activated through the use of ATP and binds to actin, then pivots to slide actin and create tension. A new ATP will then bind to the myosin cross-bridge which allows for the dissociation of myosin from actin. This cross-bridge dissociation cycle will continue as long as the calcium concentration remains high enough to inhibit the tropomyosin block. Once muscle contraction ceases, acetylcholinesterase will break down acetylcholine. This will cease muscle contraction and the intracellular calcium concentration will be actively pumped back into the sarcoplasmic reticulum. This removal of calcium will restore the inhibitory action of the tropomyosin block.

2.3 - Mental Fatigue

2.3.1 Effects of Cognitively Demanding Tasks

Mental fatigue can be described as a psychobiological state that is caused by extended or intense periods of cognitive activity (Marcora et al., 2009; also see Boksem & Tops, 2008) and often results in feelings of tiredness following exposure to a task that requires prolonged cognitive exertion. Mental fatigue can impair muscular performance during a concurrent task such as completing a mentally fatiguing task at the same time as a physical task (MacDonell and Keir, 2005) or induce carryover effects onto a subsequent physical task (Marcora et al., 2009). An alluring paper by Coutinho and colleagues (2018) examined the effects of induced mental and muscular fatigue on soccer player’s physical performance during small-sided games (soccer games with fewer players and a smaller field than normal) performed under a control, physical fatigue, and mental fatigue condition. The results suggest that muscular fatigue decreased distance covered during high speeds but increased in the moderate and low speeds. However, mental fatigue had the lowest values recorded for majority of the physical variables. This suggests that mental fatigue may cause players to fail to notice incoming information in an appropriate time frame which can affect their positioning relative to teammates, ultimately hindering the level of movement synchronization (Coutinho et al., 2018).

2.3.1.1 Concurrent Mental and Physical Fatigue Effects

Numerous studies have found links between either concurrent cognitive load and impaired muscular performance or prior cognitive exertion on subsequent physical task performance. For instance, Macdonell and Keir (2005) investigated the effects of cognitive load on isometric shoulder strength and found that concurrent cognitive load negatively affected shoulder strength when compared to the control condition that did not require concurrent cognitive demands. This indicates that concurrently performing a demanding cognitive task may interfere with muscle strength, similarly to how additional physical tasks interfere with muscle strength, which suggests that the cognitive loading may affect the central nervous system.

An alluring paper by LaGory and colleagues in 2011 aimed to examine the influence of mental fatigue on cardiovascular response to a performance challenge and to examine the effects of fatigue across four different arithmetic task difficulty levels. Participants in this study were presented with four different versions of an addition arithmetic task that differed in difficulty: easy, more difficult, even more difficult, and impossible. The low difficulty condition had participants add by 1 with a 5-second interval between numbers, the moderate difficulty condition had additions between 1 and 9 with a 5-second interval, the high difficulty condition had additions between 1 and 9 with a 2-second interval and the impossible difficulty conditions had additions between 1 and 9 with a 1-second interval. Cardiovascular responses were measured by a wrist module with an embedded sensor that was placed on the radial artery. The sensor measured the amplitude of the radial pulse and heart rate was estimated through counting the radial pulses (LaGory et al., 2011). Although this study had mixed results where the low difficulty arithmetic task group had higher systolic blood pressure and heart rate compared to the moderate and high difficult decisions, this study demonstrated that mental fatigue induced by an arithmetic task can affect physiological responses (LaGory et al., 2011). In relation to this thesis, this change in blood pressure and heart rate could translate to negatively affecting grip strength and endurance in the mental fatigue and concurrent fatigue conditions.

Additionally, a study conducted by Shortz and Mehta in 2017 investigated the impact of two different cognitive challenges with (concurrent fatigue condition) and without (mental fatigue condition) a fatiguing handgrip task on age-related changes in neuromuscular functions when compared to the control condition. The experimental task required participants to intermittently exert at 30% of their baseline grip MVC for 15 seconds. In the control condition, participants sat for 60 minutes watching a documentary or reading magazines prior to the fatiguing handgrip exercise. In the cognitive fatigue condition, participants completed 60-minutes of cognitive testing prior to the fatiguing handgrip exercise. The test included a 30-minute Stroop test followed by a 30 minute 1-Back test. In the concurrent condition, participants completed a subtraction arithmetic test while performing the fatiguing handgrip exercise (Shortz and Mehta, 2017). The study measured strength loss, endurance time, EMG, force fluctuations, mental demand, rated perceived discomfort, heart rate and heart rate variability. The results showed that concurrent mental and physical fatigue condition resulted in increases in force fluctuations, a reduction in endurance time, increased mental demand ratings and the mental arithmetic task was found to increase cognitive processing requirements during the force-matching endurance task when compared to the other conditions (Shortz and Mehta, 2017). Since the present thesis has a similar physically fatiguing task (intermittently exerting grip strength for 15 seconds) and a similar concurrent condition, these findings indicate that the arithmetic task may negatively affect endurance time and force steadiness in our research as well.

In addition to the above, concurrent exertions can lead to increases in EMG amplitude during a physical task. Lundberg et al. (2002) found that when a cognitively demanding task was performed concurrently with a static force test contraction of the trapezius muscle, EMG activity increased when compared to performing the static force test independently. Similarly, Larsson et al. (1995) found that performing a cognitively demanding task concurrently with a static force contraction resulted an 20% increase in EMG activity compared to when the static force contraction was performed independently. This increase in EMG activity that is associated with the cognitive task was also seen subsequent fatiguing contractions performed without exposure to the cognitive task (Larsson et al., 1995).

A paper by Mehta and Agnew in 2011 investigated the effects of simultaneous physical and mental demands on upper extremity muscles during static exertions. This study was conducted because, although many studies have shown that mental fatigue increases muscle tension during lower-load exertions, it was uncertain if this was the case during higher-load exertions of upper extremity muscles. The study included seventeen healthy participants who performed isometric upper extremity exertions at 5, 25, 45, 65, and 85 percent of their MVC with and without (control) a cognitively demanding task. EMG was used to quantify muscular response and motor performance was assessed with force fluctuations. The study found that a decrease in muscle activity resulted when participants performed the cognitive task and the decrease in muscle activity was greater with higher MVCs. The results from this study suggests that certain upper extremity exertions are affected by different MVC levels due to interference by a mental task (Mehta & Agnew, 2011). However, these results also suggest that concurrent mental and neuromuscular fatigue may have negative carryover effects on physical performance for subsequent tasks.

The biopsychosocial model of job stress suggests that both mental and physical stress can create physiological responses and that the combination of both stresses increase hormonal stress and muscle tension that can last long after the individual has left work (Melin and Lundberg, 1997). Mental fatigue has been associated with shorter muscle endurance, reduction in muscle strength and an increase in muscle activity through EMG recordings (Mehta & Agnew, 2012). Studies have shown that sustained muscle activity due to mental stress can lead to sustained muscle activation due to the motor units continuing to be activated. If this is coupled with muscles already being fatigued, it is logical to presume that this will have a stacking detrimental effect on muscle activity. If the same motor units are activated during physical tasks and mental tasks, they are at risk of being overloaded. Over time, this may lead to decreased motor performance that can make muscles and joints unstable while performing tasks, which creates higher risks of workplace injuries (Mehta & Agnew, 2011). This overload of motor units may lead to other detrimental effects such as impairing the ability of muscle fibers to repair themselves, increasing metabolic disturbances, increasing pain sensitivity and reducing the maximum force output of the muscle (Lundberg et al., 2002). From these studies it can be seen that mental fatigue coupled with neuromuscular fatigue can increase hormonal stress and muscle tension (Melin and Lundberg, 1997), mental stress can lead to motor units being activated even after the completion of a physical task (Mehta & Agnew, 2011) and over time this may also lead to damage to the muscle fibers (Lundberg et al., 2002). This research shows that concurrent mental and neuromuscular fatigue has the potential to have short term and long-term detrimental effects, thus indicating the need for further research on the topic.

Taken together, research shows performing a demanding cognitive task while performing a physical task negatively affects aspects of physical task performance (i.e., concurrent effects). Completing a mental task at the same time as a physical task can have an effect on heart rate, blood pressure, increases in force fluctuations, a reduction in endurance time, increased mental demand ratings and an increase in EMG amplitude. Additionally, the combination of both stresses increases hormonal stress and muscle tension that can last long after the individual has left work. In the current study, force fluctuations, endurance time, mental and physical demand ratings, and EMG amplitude will be measured. Thus, based on this previous research, we can expect to observe changes in force fluctuations, EMG amplitude and mental demand ratings after participants complete the concurrent fatigue condition.

2.3.1.2 Mental Fatigue Carryover Effects

Over the past decade, there has been a growing body of literature that has explored the carryover effects of mental fatigue (or prior cognitive exertion) on physical performance since the seminal work conducted within sport and exercise psychology (Bray et al., 2008) and exercise physiology (Marcora et al., 2009). Typically, these studies ask participants to complete a cognitively demanding task (such as an arithmetic test) to induce a state of mental fatigue prior to performing a task that requires aspects of physical performance. A recent review and meta-analysis of this literature has shown that prior cognitive exertion has significant small-to-medium sized negative carryover effects across aspects of physical task performance including endurance (aerobic and anaerobic), resistance, and motor performance (see Brown et al., 2020). Of these tasks, isometric resistance, motor, and dynamic resistance yielded the greatest negative effects due to prior cognitive exertion and had the most detrimental effect on physical tasks that required prolonged effort regulation.

A seminal paper written by Marcora and colleagues in 2009 aimed to experimentally confirm if mental fatigue worsens physical performance in humans by investigating the effect of prior cognitive exertion (to induce a state of mental fatigue) on ratings of perceived exertion and time to exhaustion during high intensity cycling (Marcora et al., 2009). This study was conducted because the effect of mental fatigue on skill performance in drivers and pilots had been researched before but the effect of mental fatigue on physical performance had not been experimentally confirmed. The study had sixteen participants that cycled until they were exhausted at 80% of their maximum power output after they were mentally fatigued by a cognitive task or after watching documentaries (control condition). The study found that participants that were mentally fatigued perceived that their effort during exercise was much higher compared to the control condition. The mentally fatigued group also reached their perceived maximum exertion level faster and stopped cycling earlier when compared to the control condition. This suggests that mental fatigue reduces exercise endurance because it causes a higher perception of effort in individuals (Marcora et al., 2009). The authors proposed this finding indicates that mental fatigue affects the central processing of the sensory inputs that the body receives which alters the perceived effort that participants can exert (Marcora et al., 2008). Pageaux (2016) expanded on this by relating the corollary discharge model to perception of effort. This model theorizes that cognitive and motor systems rely on sensory information to allow for predictive estimation of our actions. During an action, sensory-to-motor signals help to determine the brain's movement commands but at the same time, corollary discharge relays copies of these movement commands to other sensory areas to ensure they are informed of upcoming movements (Subramanian et al., 2019). The model suggests that the perception of effort is generated by neuron processes that arise from the centrifugal motor commands that are associated with the activity of premotor and motor areas of the brain responsible for voluntary muscle movement (Pageaux, 2016; Marcora et al., 2009). Previous studies have suggested that the prefrontal cortex plays a role in regulating concurrent tasks that use motor and cognitive processing (Mehta and Parasuraman, 2014). Additional cognitive demands may reduce or impair activation of the prefrontal cortex which can reduce the time to task failure for upper extremity tasks (Shortz and Mehta, 2017).

Research shows that performing a demanding cognitive task has negative carryover effects on subjective ratings of perceived exertion and physical endurance on a subsequent task performance (i.e., sequential effects). Interestingly, researchers have suggested that cognitive exertion negatively affects physical task performance due to neurophysiological alterations within areas of the brain that govern both cognitive and motor processes such as the prefrontal cortex. Research has also shown that prior physical exertion that induces neuromuscular fatigue has negative carryover effects of physical performance. In addition to this, performing a concurrent physical and cognitive fatiguing task negatively affects physical performance however, literature on this topic has not explored the carryover effects of concurrent mental and physical fatigue on physical performance. In the current study, an arithmetic test will be used to induce cognitive load on participants in the mental fatigue and concurrent fatigue conditions. As literature suggests, this should result in a decrease in the time to task failure for subsequent endurance trials and a decrease in muscle strength.

For tasks that require submaximal effort regulation over long periods of time (such as isometric handgrip endurance performance that will be used in the present study), overperceiving effort can have negative effects on an individual's performance because the person reaches their limit of perceived tolerable exertion sooner (which causes them to disengage from the task earlier). It is possible that the regulation of attention during demanding tasks may affect the performance of motor tasks, since some studies have reported that there are common underlying pathways that both physical and attentional effort use (Brown et al., 2020). It is possible that performing a demanding cognitive task in conjunction with a demanding physical task (such as the concurrent fatigue protocol in this thesis) will result in a greater accumulation of adenosine since participants are using the anterior cingulate cortex (ACC) to perform both the physical and mental tasks concurrently and correctly. In turn, ratings of perceived exertion may also be greater, eventually resulting in reduced performance in the physical outcomes. A study by Martin and colleagues (2018) expanded on Pageaux et al.'s (2014) model by suggesting that the accumulation of adenosine, resulting from prior cognitive exertion, also leads to an inhibition of dopamine release within the ACC which reduces the person's motivation to exert effort during the subsequent physical task.

A recent study by Alder and colleagues (2020) examined the impact of combining physical and mental load on anticipation of soccer players. The study had sixteen players that completed a video anticipation test in four counterbalanced conditions and measured response accuracy and visual search behavior in addition to measures of effort that were assessed throughout the condition, with 7 days between each session. The physical condition had participants complete a simulated soccer protocol on a treadmill followed by the anticipation test. The mental condition had participants complete a 30-minute Stroop test followed by the anticipation test. The concurrent condition had participants complete the soccer protocol and the Stroop Test at the same time followed by the anticipation test. The control condition had participants only complete the anticipation test. The results found that response accuracy decreased, and fixations increased in the physical condition and the mental condition when compared to the control condition. The results from the concurrent condition found when soccer players completed a 30-minute Stroop test (mental fatigue) and completed a simulated soccer protocol (physical fatigue) on a treadmill concurrently, the response accuracy decreased, fixations increased, and measures of effort increased. The physical condition and mental conditions both performed worse than the control and the concurrent condition worsened further. This study suggests that the increased load caused by the mental task impairs the ability of the players to designate enough resources to process incoming information during subsequent response accuracy. Although the study focused mainly on anticipation, it used similar experimental conditions (physical, mental, concurrent, and control) that are implemented in this thesis and used a subsequent task to measure the carryover effects of the experimental conditions which is similar to the design of this thesis.

A meta-analysis conducted by Brown and colleagues (2020) investigated the negative carryover effects of prior cognitive exertion (to induce a state of mental fatigue) on different types of physical tasks such as aerobic, resistance, maximal anaerobic and motor skills. Their review revealed that there were performance impairments for prolonged submaximal effort tasks as well as motor skill-based tasks. The review found that isometric resistance, motor, and dynamic resistance had the largest negative effect from prior cognitive exertion (such as from an arithmetic test or Stroop task) and that aerobic exercise had a smaller significant negative effect from prior cognitive exertion. Specifically, prior cognitive exertion had the most detrimental effect on tasks that required prolonged effort regulation (Brown et al., 2020). In addition to this, prolonged cognitive exertion leads to an accumulation of adenosine within the ACC which triggers higher perceptions of effort which can have negative effects on performance since the individual reaches their limit of perceived tolerable exertion sooner (Pageaux et al., 2014). The effects of neuromuscular fatigue on subsequent physical performance have been well documented, with the development of peripheral fatigue during exercise consistently resulting in decreases in muscle strength (Gandevia, 2001; Froyd et al., 2013; Shortz and Mehta, 2017; Lundberg et al., 2010). Furthermore, Pethick and colleagues (2015) found that performing fatiguing maximal and submaximal isometric contractions of the knee extensors resulted in decreases in maximal voluntary torque and an inability to sustain physical exercise over time (Pethick et al., 2015). As such, a task that this thesis will utilize also requires prolonged effort regulation as participants will need to exert their forearm muscles for a prolonged period of time after completing a cognitively demanding task often used in previous research (i.e., the arithmetic test). Our primary physical outcome will include handgrip endurance in addition to force fluctuation during the endurance task and hand grip MVCs. Previous research also indicates that the extent of mental fatigue is task dependent as more demanding cognitive tasks will result in higher levels of fatigue in less time compared to less demanding cognitive tasks (Brown et al., 2020). The Stroop task and arithmetic test are demanding cognitive tasks and therefore should result in substantial mental fatigue during the concurrent and mental fatigue protocols (Brown et al., 2020).

Taken together, the models proposed by Pageaux et al. (2014) and Martin et al (2018), suggest prior cognitive exertion negatively influences physical performance through various neurophysiological processes (increases in adenosine during the cognitive task which inhibits dopamine release) which, in turn, can lead to reduced motivation to perform a subsequent physical task, higher perceptions of effort during the subsequent physical task and, ultimately, reduced performance on that physical task. This in part, will be explored in this thesis by assessing the interactions between various combinations of fatigue (i.e., mental fatigue alone vs. neuromuscular fatigue along vs a concurrent condition) on various aspects of psychological perceptions and physical performance. While the models proposed by Pageaux et al. (2014) and Martin et al (2018) provide possible neurophysiological pathways accounting for the negative carryover effect of prior cognitive exertion on physical performance, they have not been tested in humans and therefore the precise underlying neurophysiological pathways are still largely unknown. Nevertheless, they provide some insight to common psychological factors (i.e., perceptions of exertion and motivation) that may account for the negative effects of mental fatigue on physical performance (Brown et al. 2020) and should continue to be assessed in future studies.

2.3.2 Causes

Mental fatigue can be caused by various factors including stress, prolonged or intense focus, or mentally taxing work (Lundberg et al., 2010). Mental stress can induce muscle tension which has shown to have various negative effects such as contributing to musculoskeletal disorders, impairing physical performance, and affecting muscle proprioception (Lundberg et al., 2002). Psychosocial factors such as strain from work, stress, or personal factors (Melin and Lundberg, 1997) can also affect musculoskeletal pain by increasing pain awareness and affecting recovery (Mehta & Agnew, 2013). Furthermore, exposure to psychosocial stresses have been reported to show negative physiological indicators such as increased sympathetic nerve activity. This has been more prominent in low level static work where cognitive stress has shown to negatively affect shoulder muscle activity (Mehta & Agnew, 2012). Many studies have shown that mental demands result in muscle tension in low-level exertions (Mehta & Agnew, 2011). Studies have also shown that mental demands keep low threshold motor units active. This may contribute to motor unit overuse as mental fatigue often lasts longer than muscle fatigue (Lundberg et al., 2002).

A growing body of research has found that muscle activity is higher following mental fatigue. Bray and colleagues (2008) conducted a study on the effects of self-regulatory strength deception on muscle performance and EMG activation. Their results showed that self-regulatory depletion (induced by a cognitively demanding task) negatively affected muscle activation required to sustain a 50% submaximal force production task performed to exhaustion. More specifically, for the same amount of force generation, more motor units were activated in the self-regulatory depletion group compared to the control group, meaning that when participants were depleted, they had greater muscle fatigue and performed worse on an endurance handgrip trial (Bray et al., 2008). Similarly, Graham and colleagues (2014) found increased EMG activation patterns during an endurance handgrip trial following mental imagery. The study states that the increased muscle activation that is required to exert a 50% MVC handgrip squeeze after mental imagery supports the concept that the visualization of an effortful task has the ability to induce central fatigue (Graham et al., 2014).

Furthermore, Brown and Bray (2017) investigated the effect of monetary incentives on physical endurance performance after a mentally fatiguing task with a secondary purpose to investigate the effect of mental fatigue and incentives on muscle activation during physical endurance performance. The results found that EMG amplitudes and endurance performance were relatively equal in the mentally fatiguing task incentive condition when compared to the control incentive condition and control no incentive condition. This shows that manipulating participants' motivation can not only overcome the negative effects of mental fatigue on endurance performance but restores muscle activation levels to enable participants to better perform the endurance task (Brown and Bray, 2017). Finally, Pageaux and colleagues (2015) also reported that the EMG RMS of the vastus lateralis was significantly higher following the mentally fatiguing task when compared to the control condition during a physical endurance task. They suggest that the prolonged self-regulation during the mental fatigue task alters muscle recruitment at the onset and during the subsequent endurance task (Pageaux et al., 2015). Therefore, these results combined suggest that mental fatigue can alter motor recruitment patterns during subsequent physical tasks and this thesis's protocol has potential to yield results that align to these studies.

Mental fatigue can be induced during an individual's job but often times it will continue to affect the individual after they have left the job which indicates that the motor units will continue to be used for long periods when mental fatigue is induced (Lundberg et al., 2002). This means that factors like stress that contribute to mental fatigue will keep motor units active even when then individual is not involved in physical activity. This prolonged activity of motor units that have low activation thresholds can yield metabolic disruptions and pain to the individual (Lundberg et al., 2002). This increased activity of motor units may also reduce the ability of muscles to recover from muscular fatigue because they will not get adequate rest (Lundberg et al., 2010). Muscular effort can also be reduced due to the shift of attention that is caused by mental fatigue. If a worker's mind is overloaded or stressed enough that they have been mentally fatigued, they may not have enough attentional resources to allocate to their physical task (Mehta & Agnew, 2013) because it reduces the ability of the neural drive to maintain the required force levels (Mehta & Agnew, 2012). Overall, these findings suggest that mental fatigue is associated with negative concurrent and carryover effects on various aspects of psychological perceptions and physical performance.

To summarize, mental fatigue can be caused by various factors such as stress, increased mental workload, or intense focus (Lundberg, 2002; Graham et al., 2014). In addition to this, prolonged stress has been shown to keep motor units active even if no physical stimulus is present which can lead to pain or a reduced ability to recover after neuromuscular fatigue (Lundberg, 2002). Based on this literature, central fatigue, whether caused by the mental fatigue condition or the neuromuscular fatigue condition, should produce negative carryover effects on participant’s handgrip MVCs, endurance times and EMG results. Whether prior cognitive exertion causes central fatigue is still under debate (see Bray et al., 2008; Pageaux et al., 2015) and requires additional research given the paucity of research on this topic.

2.4 - Gaps in Research

Mental fatigue and neuromuscular fatigue have been individually investigated by many different researchers. However, there are far fewer articles published comparing the effects of concurrent mental and neuromuscular fatigue on upper limb neuromechanics. In addition, we are unaware of previous research that has investigated the independent carryover effects of either mental or neuromuscular fatigue on subsequent physical performance in addition to the combined effects of both mental and neuromuscular fatigue on subsequent physical performance within a single study (i.e., a study including a control condition, a mental fatigue condition, a neuromuscular fatigue condition, and a combined mental and neuromuscular fatigue condition). There have also been inconsistencies across experimental conditions that limits that ability to draw conclusions on these effects.

As far as we are aware, only two studies have assessed the carryover effects of concurrent mental and neuromuscular fatigue on subsequent physical performance. Mehta and Agnew (2012) only assessed concurrent mental and neuromuscular fatigue on MVCs, and Shortz and Mehta (2017) included a concurrent, physical and cognitive condition but only measured pre- and post-handgrip MVCs. The study by Shortz and Mehta (2017) assessed the extensor carpi radialis and flexor carpi radialis with EMG during all three conditions and MVCs.

The results showed that the concurrent condition resulted in higher strength loss in both younger and older adults when compared to the cognitive fatigue and control conditions (Shortz and Mehta, 2017). While these are valuable studies, the study designs did not include a full factorial that compared all four possible conditions in a single study (i.e., a control condition, a mental fatigue condition, a neuromuscular fatigue, and a concurrent mental and neuromuscular fatigue condition). Additionally, while the studies provided some indication of the potential negative carryover effects of a concurrent mental and neuromuscular fatigue manipulation on muscle strength (i.e., MVCs), the effects of a concurrent manipulation on subsequent muscular endurance performance, as well as force fluctuation patterns and muscle activity patterns during the endurance task, remain unknown. Thus, additional research is needed to determine the interactive effect that mental and muscle fatigue have on physical performance, both independently and concurrently.

2.5 - Conclusion of Literature Review

Neuromuscular fatigue and mental fatigue have both been extensively researched individually and there are emerging studies that focus on their effects on concurrent physical performance. However, further research is needed on their combined effects on subsequent physical performance, as both exposures are common in many occupational tasks.

Neuromuscular fatigue results in decreases in muscle performance which can be attributed to central fatigue that impairs signal transmission from the brain to the muscle and peripheral fatigue that may be caused by inhibitory responses to metabolite accumulation or the depletion of neurotransmitters in the NMJ. Findings from research on mental fatigue also strongly support negative effects on physical performance due to stress, increased mental workload, or intense focus to induce central fatigue. Performing a demanding cognitive task while performing a physical task negatively affects aspects of physical task performance such as force fluctuations and endurance times, both during a concurrent task and in subsequent physical measurements. While there have been previous studies that have assessed the carryover effects of concurrent mental and neuromuscular fatigue on subsequent physical performance, there is a gap in the literature on the carryover effects. Specifically, the independent carryover effects of either mental or neuromuscular fatigue on subsequent physical performance, in addition to the combined effects of both mental and neuromuscular fatigue on subsequent physical performance, has not been explored within a single study.

2.5.1 Research Question

Does concurrent mental and physical fatigue have a greater impact on physical performance compared to mental and physical fatigue alone?

2.5.2 Hypotheses

In this pilot study, we hypothesized that mental fatigue would have a negative impact on physical performance when compared to the control condition, neuromuscular fatigue will have a negative impact on physical performance when compared to the control condition, and the combination of mental and neuromuscular fatigue will yield the greatest detrimental effects on physical performance when compared to the mental fatigue, muscle fatigue, and control conditions independently.

The following hypotheses were tested in this pilot study:

1. Concurrent fatigue has the greatest negative impact on physical performance compared to physical and mental fatigue alone and the control condition.
2. Physical fatigue has a greater negative impact on physical performance compared to mental fatigue and the control condition.
3. Mental fatigue has a greater negative impact on physical performance compared to the control condition.
4. The control condition will have little to no negative impact on physical performance.

Chapter 3

3.1 - Methods

3.1.1 Participants

For this pilot study, a total of 4 participants were recruited consisting of three males (n=3) and one female (n=1) between the ages of 18-35. All participants were free from shoulder and forearm injury and/or pain in the last 12 months. In the full study, we will recruit a total of 24 participants with an equal number of males (n=12) and females (n=12) attending Ontario Tech between the ages of 18-35. Participants who experienced shoulder and forearm injury or pain in the past 12 months, are varsity level athletes, or use an implanted electronic device will be excluded from recruitment.

3.1.2 Study Design

This pilot study evaluated four separate experimental conditions in a within-subject repeated measures design. As such, each participant visited the lab on four separate days to complete each fatigue condition (i.e., control, mental, physical and combined mental & physical) in a counter-balanced order (quasi-randomized) to ensure participants had a randomized order in which session they completed each condition and no two participants completed the same sequence of conditions (Table 1). Each session was separated by at least 3 days to allow for adequate recovery.

Table 1: Participant conditions by session. Conditions were assigned to each participant in a quasi-randomized order.

	Participant 1	Participant 2	Participant 3	Participant 4
Session 1	Physical	Mental	Control	Physical + Mental
Session 2	Control	Physical +Mental	Mental	Physical
Session 3	Physical + Mental	Control	Physical	Mental
Session 4	Mental	Physical	Physical + Mental	Control

3.1.3 Data Acquisition and Instrumentation

3.1.3.1 Handgrip Transducer

A Lorenz Messtechnik K-2565 handgrip transducer was utilized to obtain grip forces. Signals were sampled at 2000 Hz using a National Instruments analog to digital card and smoothed using a half-second moving average. Real time visual presentation of this signal was provided on a monitor located in front of the participant using custom LabView software.

3.1.3.2 Electromyography

Surface electromyography (sEMG) was used to record muscle activity for the flexor carpi radialis and the extensor carpi radialis of the dominant arm. Disposable bipolar Ag/AgCl surface electrodes with foam adhesive hydrogel (disc-shaped, 3 cm radius; Meditrace 130, Kendall, Mansfield, MA, USA) were placed on the skin overlaying the muscle belly after shaving, abrading and cleaning the area with an isopropyl alcohol swab. sEMG was detected and amplified using a Bortec AMT-8 system and was sampled at 2000 Hz with the National Instruments A/D card.

3.1.3.3 Ratings of Perceived Exertion (RPE)

Following each handgrip endurance task (before and after the experimental manipulation), participants rated their perceived physical exertion using Borg's CR-10 (Borg, 1998) scale, ranging from 0 (*nothing at all*) to 10 (*absolute maximum*), in order to determine the extent to which they exerted their maximum effort.

3.1.3.4 Perceived Mental Fatigue (PMF) and Perceived Physical Fatigue (PPF)

Participants rated their perceived individual mental fatigue (PMF scale) and physical fatigue (PPF scale) following baseline measurements, each endurance trial (pre and post experimental manipulation) and every three minutes during the experimental manipulations to observe the progression of both mental and physical fatigue throughout the experimental manipulation. The PMF and PPF are two separate scales (see Appendix J) that ask participants to rate their perceived mental fatigue and perceived physical fatigue, respectively. These measures are based off the visual analogue scale (VAS) by Wewers & Lowe (1990). Participants were tasked with marking the point on the line that represents their current state of mental and physical fatigue respectively. Participants marked an "X" along a 100mm line between 0 (no fatigue) on the left side to 100 (maximum fatigue) on the right side to indicate their perception of their current state of mental and physical fatigue, respectively. The scores were calculated by measuring the distance in millimeters that the "X" was placed from the left side of the scale. To assess the cumulative effects of the cognitive (PMF) and physical (PPF) manipulations, these scores were recorded at baseline, after the first endurance trial, at the 3, 6-, 9-, 12-, and 15-minute time points of the experimental manipulation, and after the second endurance trial.

3.1.3.5 Feeling Scale (FS)

The Feeling Scale is a 11-point bipolar scale developed by Hardy and Rajeski (1989) and is used to measure the participant's overall affective state ranging from very good (+5) to very bad (-5) or neutral (0) in the middle. Participants were asked to report how they were feeling after the baseline MVCs, after the first handgrip endurance task, every three minutes during the experimental manipulation, and after the second endurance trial. Previous studies have shown that responses to the Feeling Scale will vary depending on exercise intensity. For example, as exercise intensity increases, participants report more negative responses compared to before they started the exercise (Hardy and Rajeski, 1989; Parfitt et al., 2000; Rose and Parfitt, 2008).

3.1.3.6 Intrinsic Motivation Inventory (IMI)

The effort and importance subscale from the Intrinsic Motivation Inventory (IMI) was used to assess participants' motivation to complete the handgrip endurance trials (Ryan, 1982). The effort and importance subscale is a 5-item measure that requires participants to indicate how much they agree on a scale from 1 (not true) to 7 (very true) on each of the items presented. These items range from how much effort the participant will put into the task, how hard they will try, how important it is to succeed at the task and if they will put a lot of energy into the task. The participant completed the IMI two times during each study visit, once before each endurance trial.

3.1.3.7 Task Self-Efficacy (TSE)

Based on recommendations by Bandura (2006), self-efficacy for performing the second endurance trial in this study was assessed using an eight-item scale used in previous research (Graham & Bray, 2015). Specifically, the task self-efficacy scale asked participants to state their confidence in their ability to perform the second endurance task compared to the first endurance task. The individual items represented hierarchical gradations of performance that were relative to the participant's performance on the first endurance trial. The scale began at 25% as long as last time and increased by 25% at each interval up to 200% as long as last time (double the amount) (see Appendix G). Participants rated their confidence for each item using an 11-point scale ranging from 0 (0% confident) to 10 (100% confident). The task self-efficacy scale was completed prior to the second endurance trial during each experimental session.

3.1.4 Procedure

3.1.4.1 Procedure Overview

Upon arrival for the experimental session, participants were instrumented with surface EMG (as described in 3.1.3.2). Next, a quiet noise trial was collected for both the sEMG and handgrip transducer for the purposes of de-biasing both signals. Following the noise trial, participants performed three handgrip MVCs with 2 minutes of rest between each MVC and one MVC for wrist extension and flexion for baseline EMG measurements. All MVCs were conducted in a standardized posture of a neutral shoulder and 90 degrees of elbow flexion. The handgrip transducer remained in a vertical orientation at a constant location on the table, promoting a neutral pronation/supination posture (Figure 1).

Figure 1: Participant interaction with the handgrip transducer in the standardized posture.

On the first day only, participants completed a 10 second practice endurance trial, to familiarize themselves with matching grip-force with the visual feedback presented on the screen. Participants then rested for another 3 minutes and completed the IMI, PMF, PPF and FS scales. Following the rest period, participants completed the first handgrip endurance trial followed by ratings of RPE, PMF, PPF, and FS.

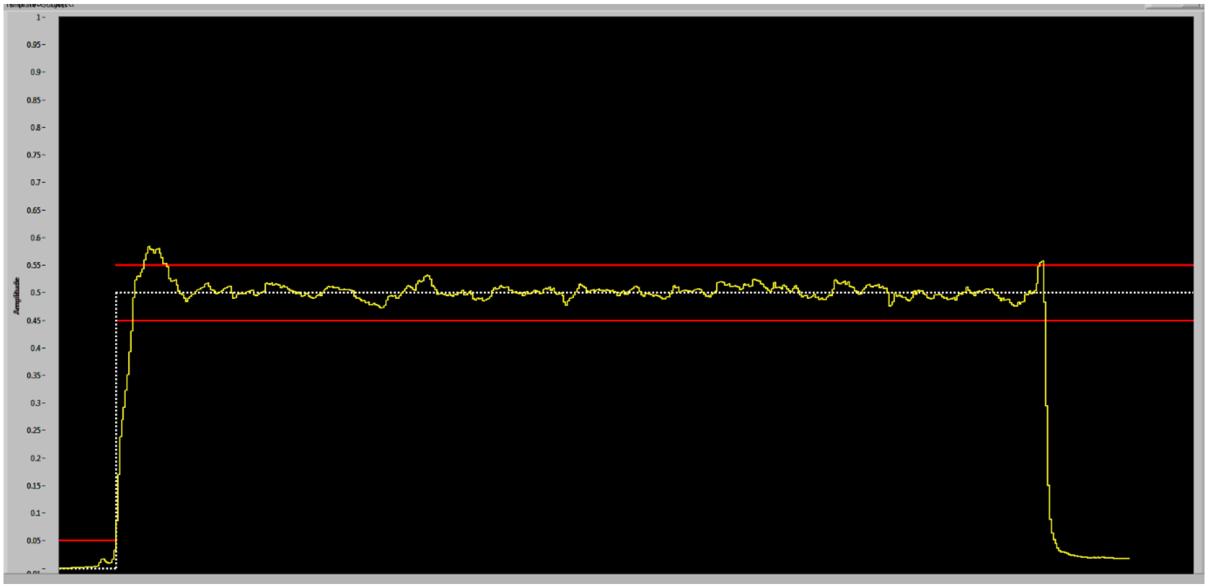

Figure 2: Participant's view of the endurance trial program.

Participants then completed an MVC followed by their respective experimental manipulation (EM) (as described in 3.1.5 below) and provided ratings of PMF, PPF, and FS at 3-minute intervals throughout the experimental manipulation. For the control condition and mental fatigue condition only, participants completed a 15 second exertion at 15.3% MVC at the start, middle (7.5 minutes) and end of the experimental manipulation.

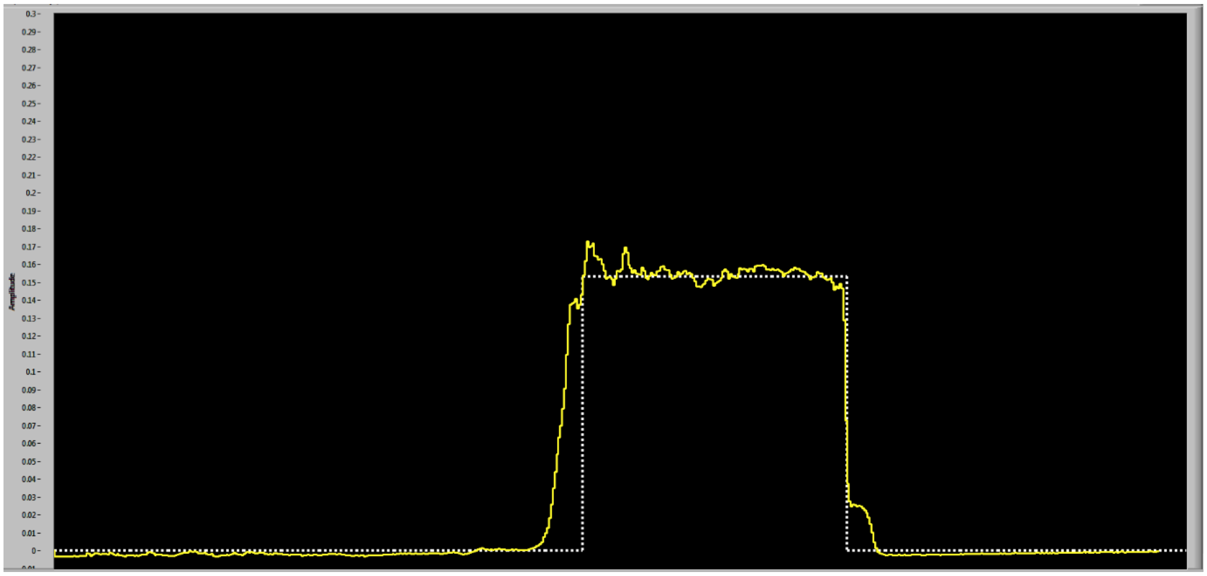

Figure 3: Participant's view of the experimental manipulation program. The yellow line scrolled across the screen. Once arriving at the end of the screen (as shown), the yellow trace history disappeared and started from the beginning (i.e., left side) again.

Following the experimental manipulation, participants performed an MVC and had 3 minutes to rest while they completed the IMI and the TSE. Participants then completed the second handgrip endurance trial followed by ratings of RPE, PMF, PPF, and FS. Once these ratings were completed, the experimenter then assisted the participants in removing the sensors and electrodes, and the experimental session was concluded for that day.

3.1.4.2 Procedure Diagram

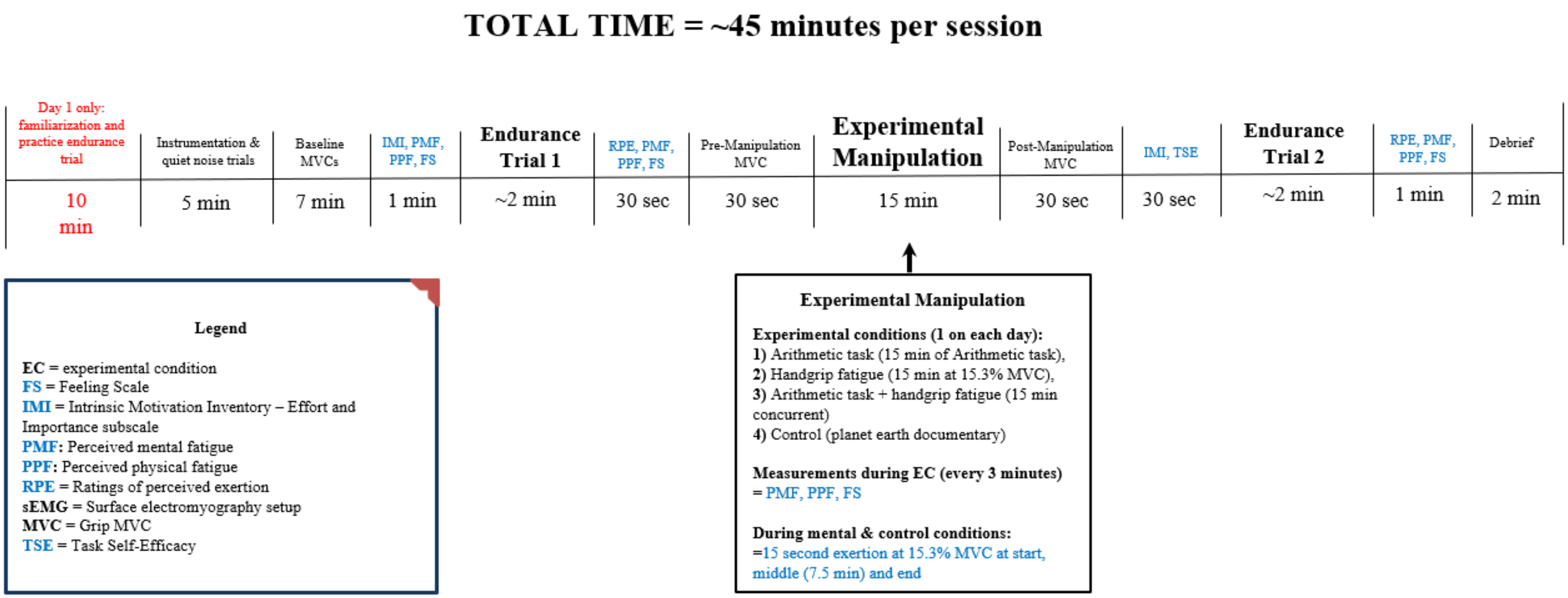

Figure 4: Overview of the experimental protocol

3.1.5 Experimental Manipulations

The study consisted of four experimental conditions, which differed based on the type of fatigue exposure that was be presented and were 15 minutes in length. Each session consisted of baseline measurements, and then the participants were counterbalanced and randomized to perform a mental fatigue protocol (i.e., arithmetic test), a neuromuscular fatigue protocol (i.e., intermittent isometric handgrip squeezes), a combined arithmetic test plus handgrip fatigue protocol, or a control condition (i.e., watching a documentary). Physical performance outcomes measured were handgrip strength, handgrip endurance, as wells as sEMG and force fluctuation data during the endurance handgrip trials.

3.1.5.1 Neuromuscular Fatigue Condition

Participants performed an intermittent isometric handgrip fatigue protocol which required them to squeeze a handgrip transducer (as described in section 3.1.6.1 below) with their shoulder adducted, elbow flexed at 90 degrees and wrist between 0 and 30 degrees flexion (Roberts, 2011) at 15.3% of their baseline MVC as this is the maximum acceptable effort recommended for a 50% duty cycle (Potvin, 2012), for 15 seconds followed by 15 seconds of rest for a total of 15 minutes.

3.1.5.2 Mental Fatigue Condition

Consistent with previous research (Mehta and Parasuraman, 2014), a mental arithmetic task was used to induce mental fatigue. Participants performed an arithmetic test which required them to verbally count backwards by sevens from a random number between 400-1000. The starting number changed every three minutes during the experimental manipulation. For example, participants may start with the number 900, subtracting in intervals of 7 and then later change to start with the number 759, subtracting in intervals of 7. This was done to ensure participants did not pick up patterns when subtracting and to keep the task as mentally fatiguing as possible. The participant's accuracy was not recorded, and participants were monitored to ensure they adhered to the task as closely as possible, but any mistakes made were not corrected. Participants performed the arithmetic task during the mental fatigue condition as well as the concurrent fatigue condition for 15 minutes. During the mental fatigue and concurrent fatigue (see 3.1.5.3 below) experimental manipulations, participants completed a 15 second exertion at 15.3% MVC at the start, middle (7.5 minutes) and end of the experimental manipulation for the purposes of tracking EMG and force outcome variables during the manipulation. Participants were familiarized with the arithmetic test each time prior to beginning the experiment.

3.1.5.3 Concurrent Fatigue Condition

Participants performed the intermittent isometric handgrip task (15 seconds exertion followed by 15 seconds rest) as well as the arithmetic test concurrently for 15 minutes.

3.1.5.4 Control Condition

Participants watched a 15-minute documentary film on YouTube "Our Planet | Fresh Water" (https://www.youtube.com/watch?v=R2DU85qLfJQ&t=5s), and completed a 15 second exertion at 15.3% MVC at the start, middle (7.5 minutes) and end of the experimental manipulation. This documentary video manipulation has been used in previous research as a control condition (Brown & Bray, 2017).

3.1.6 Primary Outcome Measures

3.1.6.1 Handgrip Strength (MVCs)

Handgrip strength was measured at various time points during the session by measuring the participant's MVCs. Handgrip force signals were smoothed using a half-second moving average using an experimental program coded by Dr. La Delfa that determined the peak force values for each MVC. Participants performed three baseline MVCs at the beginning of each session, one MVC before starting the experimental manipulation (pre-manipulation MVC) and one directly after the experimental manipulation (post-manipulation MVC). MVCs were collected by squeezing a handgrip transducer as hard as possible for approximately 5 seconds to record the force values. During this task, participants were seated with their hand grasping a handgrip transducer. This dynamometer has a force sensor embedded within, which allows for real-time force measurement of grip strength. The two highest baseline MVCs were averaged and then compared against the pre-manipulation MVC and post-manipulation MVC.

3.1.6.2 Handgrip Endurance Time to Exhaustion

Handgrip endurance time was measured at two timepoints during each session, once before the experimental manipulation (pre) and once after the experimental manipulation (post). During the endurance trial, participants exerted and maintained 50% MVC (according to the baseline MVC) by squeezing the handgrip transducer for as long as they were able, until exhaustion. Participants had a screen in front of them that showed a white dotted target line (50% MVC), as well as two solid red lines that that represented an acceptable maximum and minimum target range (55% MVC and 45% MVC respectively). Participants were tasked with keeping the force value line as close to the 50% white dotted line as possible while staying within the red lines. The threshold for the start of an endurance trial was determined when the force exceeded at least 45% MVC for 1 second and the end of the endurance trial was determined to be the time point at which the force dropped below 45% MVC for at least 1 second. The endurance time was recorded for both the pre-manipulation endurance trial and the post-manipulation endurance trial and the difference in time was compared between the pre-post endurance trials to measure the difference in endurance performance.

3.1.6.3 Handgrip Endurance Force Fluctuation

Force fluctuations were measured from the handgrip force data collected from the endurance trials. Force fluctuation was calculated by computing the coefficient of variation between a defined 5-second window length during the beginning and end, as well as the 25%, 50%, 75%, time points of the endurance trials. The change in force fluctuation was compared between the pre-manipulation and post-manipulation endurance trials. Force fluctuations were compared against the control condition to assess if the mental, neuromuscular or concurrent conditions had an effect on force fluctuations.

3.1.6.4 Muscle Activity

Muscle activity was measured during the endurance trials (pre-manipulation and post-manipulation) and during the control and experimental manipulations. We tracked the activation of the flexor carpi radialis (FCR) and extensor carpi radialis (ECR), which have been used in similar previous research evaluating grip force exertions (Mehta and Parasuraman, 2014).

3.1.7 Data Analysis

For this pilot analysis, pre to post change scores were calculated by comparing post measurements to the mean of the pre-measurements across all the conditions. Due to the low participant count, the pre to post comparisons were extremely sensitive to individual variation. As such, for the primary outcomes, normalizing to the mean of all pre-conditions for each participant was found to stabilize the comparisons for this pilot data analysis.

3.1.7.1 Force Fluctuation

Force fluctuation data were recorded using a 5-second window length during the beginning and end, as well as the 25%, 50%, 75%, time points of the endurance trials and experimental manipulations. Force fluctuations were computed via coefficient of variation over the 5-second windows.

3.1.7.2 EMG Root Mean Square (RMS) Amplitude

sEMG signals were smoothed using a 250 ms root-mean-square (RMS) window. For baseline MVC trials, the RMS signals were additionally smoothed with a half-second moving average before obtaining the peak amplitude from each channel for EMG normalization (Chopp et al., 2010). Mean normalized RMS amplitudes were taken from a 2.5-second window length during the beginning and end, as well as the 25%, 50%, 75%, time points of the endurance trials, as well as the experimental manipulations.

3.1.7.3 EMG Mean Power Frequency (MnPF)

MnPF was determined using fast fourier transformations computed in 0.5 second window lengths with 50% overlap. From these smoothed MnPF signals, average MnPF within a 2.5

second window length during the beginning and end, as well as the 25%, 50%, 75%, time points of the endurance trials and experimental manipulations were computed.

3.1.8 Statistical Analysis

As this pilot study was extremely underpowered (n=4), traditional statistical hypothesis testing was omitted and trends in the data are explored descriptively. MVC force was evaluated as the percent change in force from pre- to post-EM when compared to baseline values. Endurance time results were separately evaluated as pre-post comparisons due to the experimental manipulation. EMG amplitude, MnPF, and force fluctuations were evaluated within the experimental manipulation (analyzing the start, middle and end of the experimental manipulation) and endurance trials (beginning, 25%, 50%, 75%, and end) to observe how these measures and the subjective ratings changed within the experimental manipulation and endurance trials for each condition.

3.2- Results

3.2.1 Manipulation Checks

3.2.1.1 Perceived Mental Fatigue (PMF) Ratings

Descriptive statistics for PMF scores are shown, by condition, in Table 3. When comparing the mean PMF ratings for the concurrent and mental conditions, they exhibited similar PMF ratings with the concurrent condition (35.9±16.7) and mental condition (33.1±21.4) having more than twice as high PMF ratings when compared to the control condition (12.4±10.7). For the mental, physical and concurrent conditions, PMF ratings peaked at the 15-minute mark during the experimental manipulation (Figure 5).

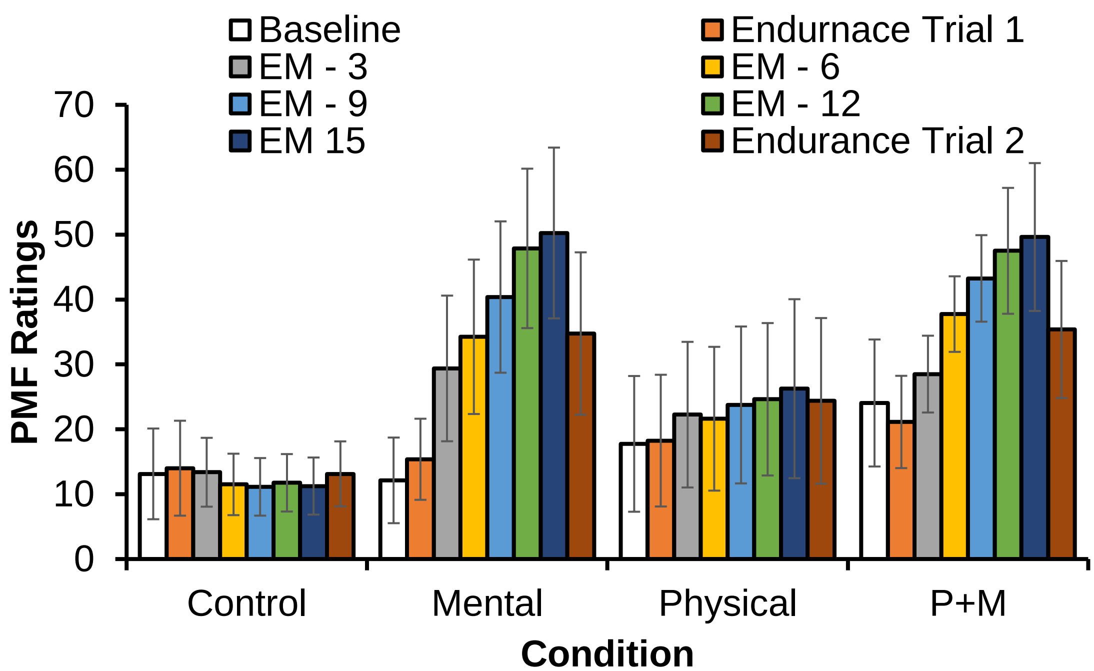

Figure 5: PMF ratings throughout a session for each condition. Error bars are presented in standard error (n=4). PMF = perceived mental fatigue, EM=experimental manipulation followed by time point in minutes, P+M = physical and mental.

3.2.1.2 Perceived Physical Fatigue (PPF) Ratings

Descriptive statistics for PPF scores are shown, by condition, in Table 3. When comparing the mean PPF ratings for the physical and concurrent conditions, they exhibited similar PPF ratings to each other with the physical condition (33.9±18.3) and concurrent condition (35.7±15.5) having almost twice as high PPF ratings when compared to the control condition (17.3±10.3). For the mental, physical and concurrent conditions, PPF ratings peaked at the 15-minute mark during the experimental manipulation (Figure 6).

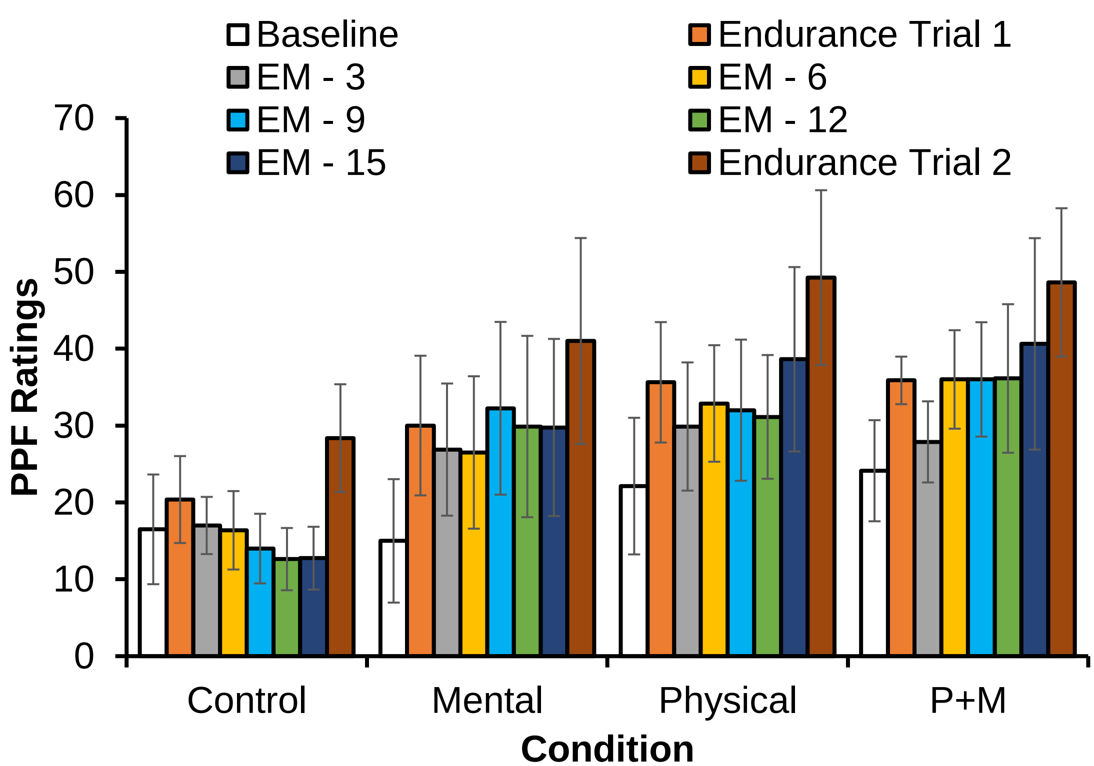

Figure 6: PPF ratings throughout a session for each condition. Error bars are presented in standard error. PPF = perceived physical fatigue, EM=experimental manipulation followed by time point in minutes, P+M = physical and mental.

3.2.2 Primary Outcome Measures

3.2.2.1 Endurance Time

Descriptive statistics for endurance times are shown, by condition, in Table 2. The mean participant endurance time was 56.6±21.2 seconds for endurance trial 1 and 51.7±13.6 seconds for endurance trial 2. The largest change in endurance time was observed for the physical condition, followed closely by the concurrent condition which showed decreases of 7.9% and 7.7%, respectively. The concurrent condition was expected to have the largest change in endurance time but the difference between the concurrent and physical conditions is minimal. The mental and control conditions were also observed to have decreases in endurance time with decreases of 3% and 2% respectively between pre-post endurance times (Figure 7).

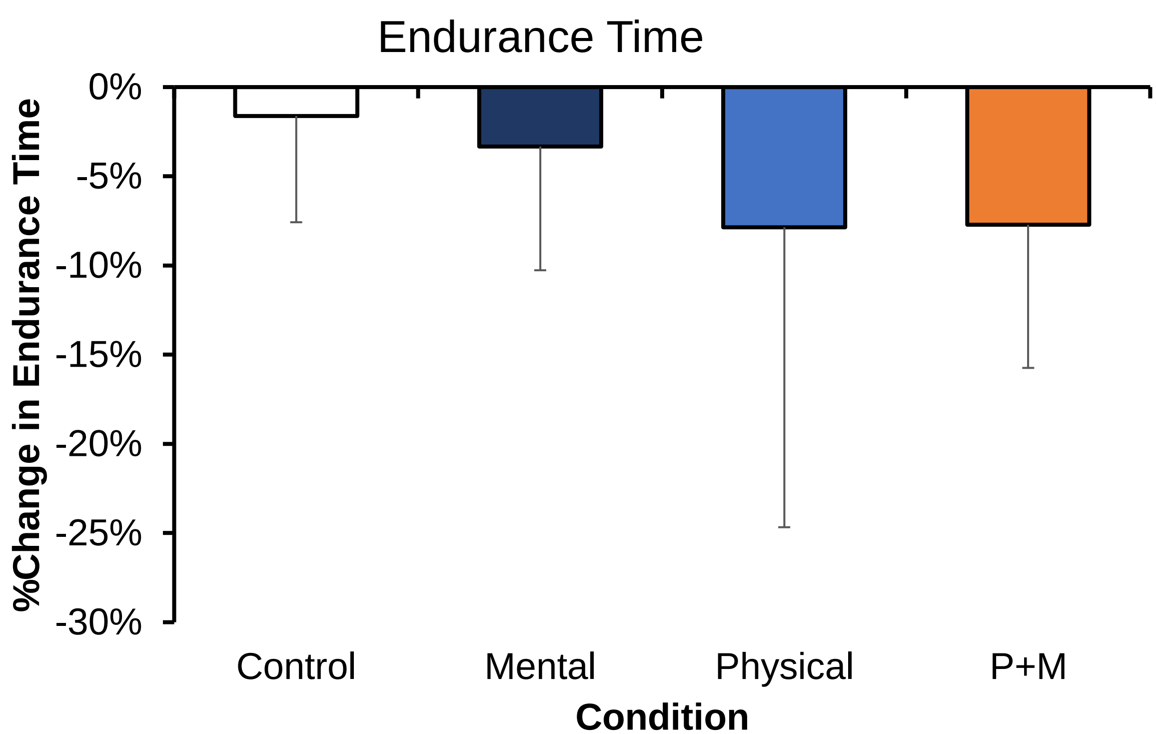

Figure 7: Percent change in endurance time from pre- to post-EM. Error bars are presented in standard error. P+M = physical and mental.

3.2.2.2 MVC

Descriptive statistics for MVCs are shown, by condition, in Table 2. The mean participant handgrip MVC force was 454±53.3N at baseline, 422±33.3 N pre-experimental manipulation and 403±61.8 N post-experimental manipulation. Note that the Pre-EM MVC was taken following the initial Endurance Trial, which explains the average decrease in the pre-EM (-6.5%) in all conditions relative to baseline. As such, there is a focus on the change in MVC due to the experimental manipulation condition. As expected, the largest pre-post difference was observed for the concurrent condition, followed by the physical condition, which showed decreases in MVC of 14% and 10%, respectively. Comparatively, the control and mental conditions resulted in similar, but minimal, 2% increases in MVC pre to post (Figure 8).

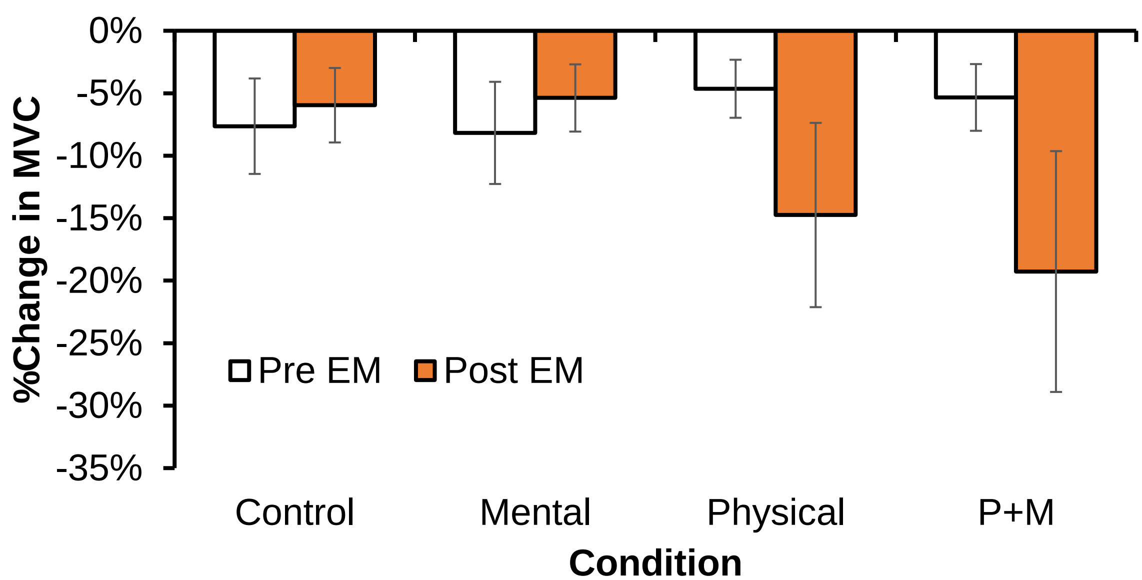

Figure 8: Percent change in force from pre- to post-EM compared to baseline values. Error bars are presented in standard error. EM=experimental manipulation, P+M = physical and mental.

3.2.2.3 Force Variability

Descriptive statistics for force variability are shown, by condition, in Table 2. The mean participant force variability was 4.85%±2.43% for endurance trial 1 and 4.72%±2.06% for endurance trial 2. The largest change in force variability was observed in the mental condition which showed an increase of 20% between the pre-post endurance trials with the physical condition also increasing minimally by 4%. Interestingly, the concurrent condition had a decrease of 17% between the pre-post endurance trials, suggesting this condition decreased in force variability between endurance trials (Figure 9). It was hypothesized that the concurrent condition would display the most force variability out of all the conditions however the concurrent condition had the least amount of force variability out of all the conditions.

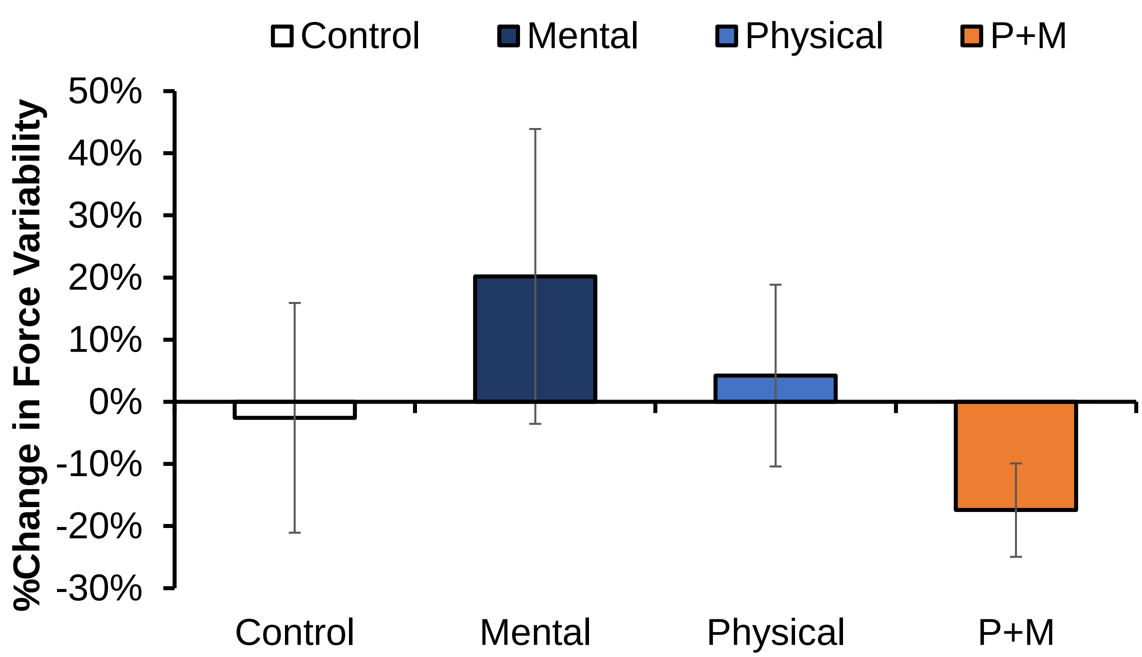

Figure 9: Percent change in force variability from pre- to post-EM. Error bars are presented in standard error. P+M = physical and mental.

3.2.2.4 Absolute Error (Performance Error)

Descriptive statistics for absolute error (performance error) are shown, by condition, in Table 2. Absolute error measures the overall deviation of the participant's force values without considering direction when compared to the target force (50% MVC) during the endurance trials. The mean participant performance error was 2.68%±1.61% for endurance trial 1 and 2.50%±1.44% for endurance trial 2. The largest change in performance error was observed in the concurrent condition which showed a decrease of 18% between the pre-post endurance trials with the physical condition also decreasing by 8%. Interestingly, the control condition had an increase of 6% between the pre-post endurance trials (Figure 10). Performance error was expected to increase the most for the concurrent condition and also increase for the physical and mental conditions. However, these results show that performance error decreased for the concurrent and physical condition, which is opposite of what was hypothesized. Furthermore, the mental condition had a minuscule increase in performance error.

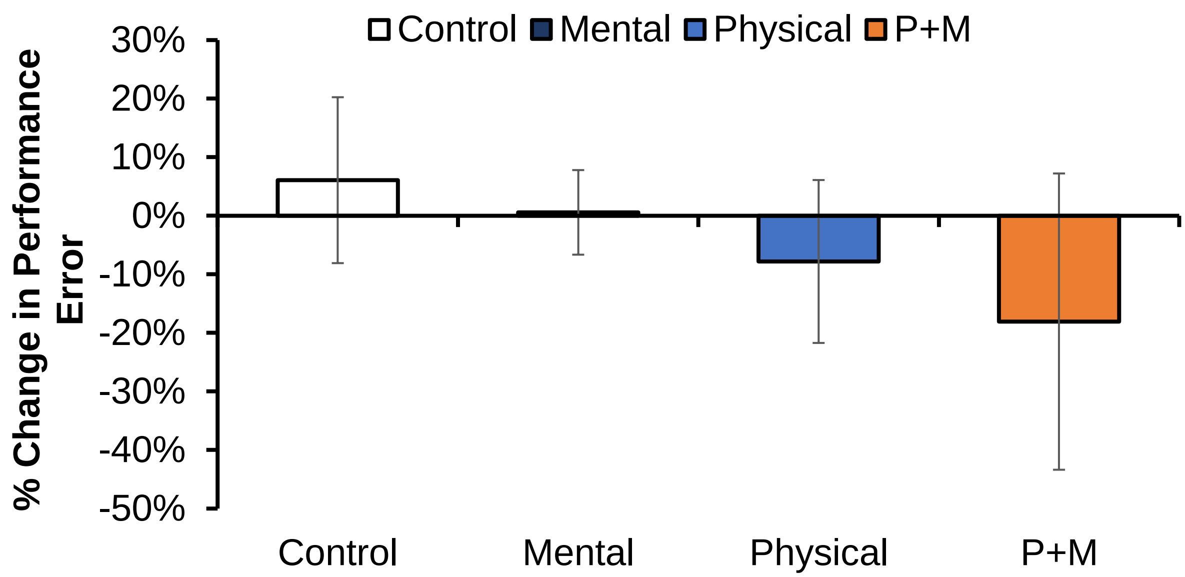

Figure 10: Percent change in performance error from pre- to post-EM. Error bars are presented in standard error. P+M = physical and mental.

3.2.2.5 aEMG

3.2.2.5.1 Endurance Trial EMG Amplitude (aEMG)

Descriptive statistics for endurance trial aEMG are shown, by condition, in Table 2. The mean participant aEMG at endurance trial 1 was 23.3±10.5 %MVE (percent of maximum voluntary excitation) for FCR and 44.4±10.8 %MVE for ECR. The mean participant aEMG at endurance trial 2 was 25.9±14.3 %MVE for FCR and 45.3±11.4 %MVE for ECR.

The ECR displayed an increase in aEMG for the physical (12%), mental (2%), and concurrent (1%) conditions between endurance trial 1 and 2 but a decrease in the control (-9%) condition between endurance trial 1 and 2 (Figure 11). The FCR displayed an increase in aEMG for the physical (68%) and concurrent (3%) conditions but a decrease in the mental (-11%) and control (-15%) conditions between endurance trial 1 and 2 (Figure 12).

When looking at the ECR and FCR side by side, an intriguing result was that the FCR had a very high change in aEMG in the physical condition, over five times greater than the ECR in physical condition. Contrary to our hypothesis, the control condition had a decrease in aEMG in both muscles in addition to the FCR in the mental condition that also had a decrease in aEMG (Figure 13).

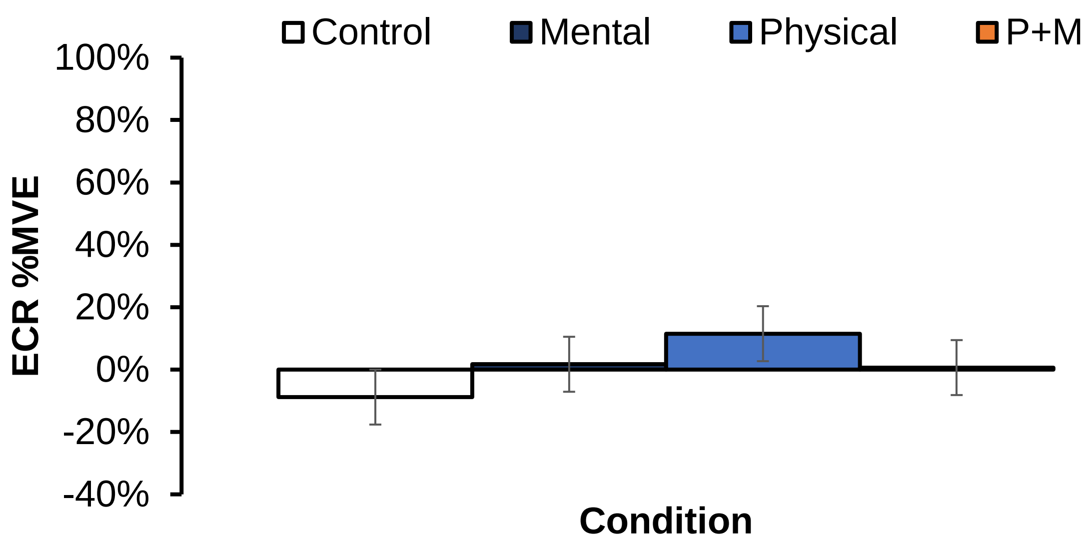

Figure 11: Percent change in aEMG between endurance trial 1 and endurance trial 2 for the ECR. Error bars are presented in standard error. ECR = extensor carpi radialis, %MVE = percent of maximum voluntary excitation, P+M = physical and mental.

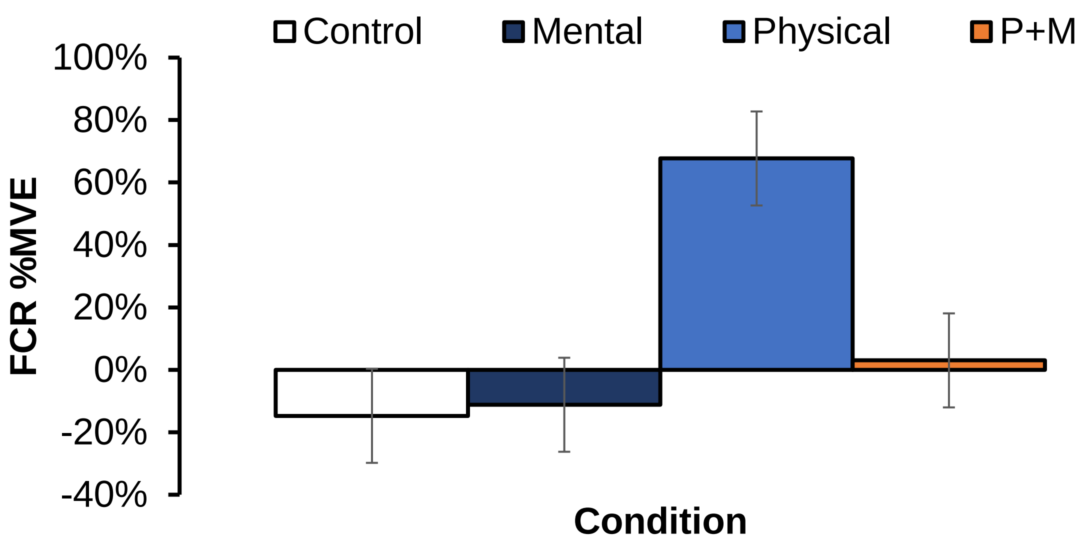

Figure 12: Percent change in aEMG between endurance trial 1 and endurance trial 2 for the FCR. Error bars are presented in standard error. FCR = flexor carpi radialis, %MVE = percent of maximum voluntary excitation, P+M = physical and mental.

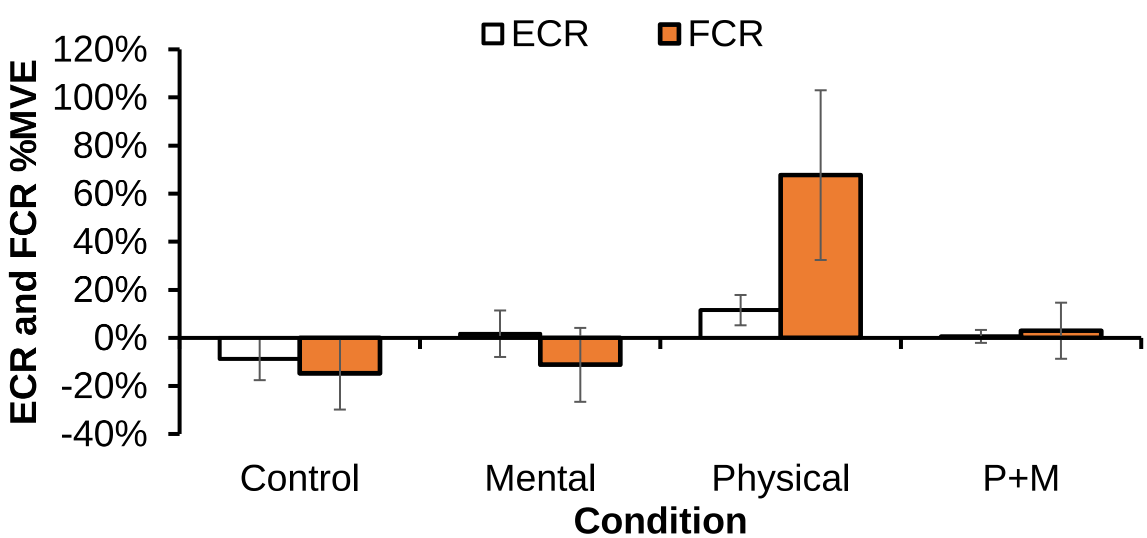

Figure 13: Percent change in aEMG between endurance trial 1 and endurance trial 2 for both the FCR and ECR. Error bars are presented in standard error. ECR = extensor carpi radialis, FCR = flexor carpi radialis, P+M = physical and mental.

3.2.2.5.2 Experimental Manipulation aEMG

Descriptive statistics for experimental manipulation aEMG are shown, by condition, in Table 2. As expected, during the experimental manipulation, aEMG increased for all conditions for the ECR muscle. The mean participant aEMG during the control condition was observed to peak during the middle of the experimental manipulation, increasing from 14.0±4.19 %MVE, to 21.0±18.6 %MVE, back down to 15.1±3.24 %MVE for the start, middle and end of the experimental manipulation respectively. The control condition was expected to have a minimal increase in muscle activity but interestingly there was a big spike in the middle of the EM. The physical condition gradually increased in aEMG throughout the experimental manipulation, increasing from 13.4±2.55 %MVE, to 17.0±7.7 %MVE, to 18.0±6.02 %MVE for the start, middle and end of the experimental manipulation respectively. The mental and concurrent conditions displayed similar results. The mental condition increased from 12.8±2.41 %MVE, to 15.3±2.27 %MVE and decreased to 14.2±1.96 %MVE for the start, middle and end of the experimental manipulation respectively. The concurrent condition increased from 13.0± 3.56 %MVE, to 15.0± 4.54 %MVE and decreased to 14.2± 4.07 %MVE for the start, middle and end of the experimental manipulation respectively (Figure 14).

During the experimental manipulation, aEMG increased for the concurrent and mental conditions as expected, however aEMG decreased minimally for the control and physical conditions for the FCR muscle. The concurrent condition decreased from 9.51±5.14 %MVE to 9.30±5.53 %MVE then increased to 9.58±5.68 %MVE for the start, middle and end of the experimental manipulation, respectively. The mental condition increased from 7.56±4.26 %MVE, to 7.82±4.01 %MVE to 8.33±3.81 %MVE for the start, middle and end of the experimental manipulation, respectively. The control condition remained equal throughout the experimental manipulation, increasing from 5.83±2.79 %MVE to 5.87±2.97 %MVE and then a slight decrease to 5.76±2.85 %MVE for the start, middle and end of the experimental manipulation, respectively. The physical condition had a slight decrease throughout the experimental manipulation, decreasing from 11.75±5.53 %MVE to 10.78±6.33 %MVE, then increasing to 11.67±7.66 %MVE for the start, middle and end of the experimental manipulation respectively (Figure 15).

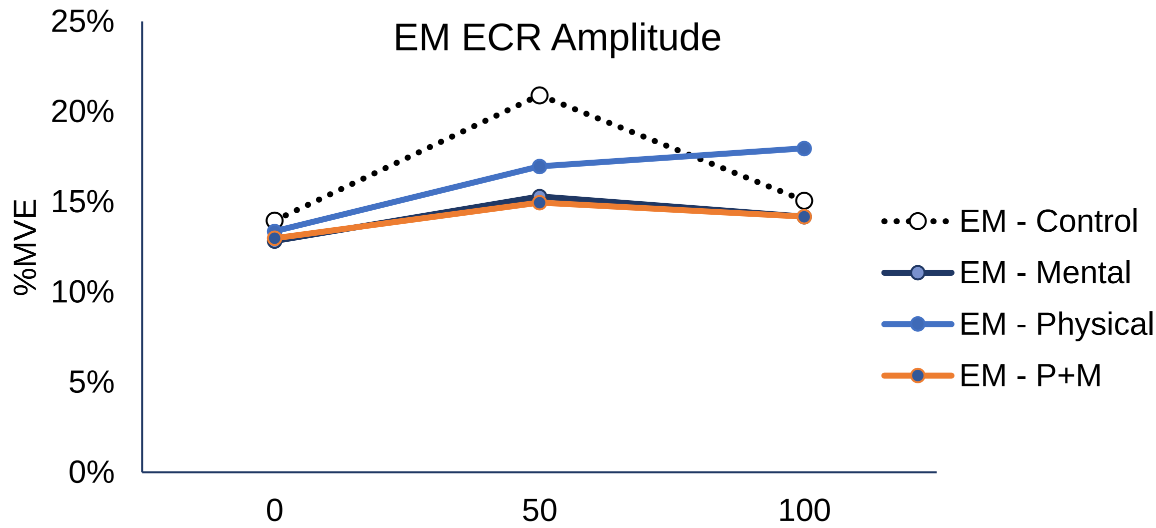

Figure 14: Mean aEMG of the ECR during the experimental manipulations. %MVE = percent of max voluntary excitation, EM=experimental manipulation, ECR = extensor carpi radialis, P+M = physical and mental.

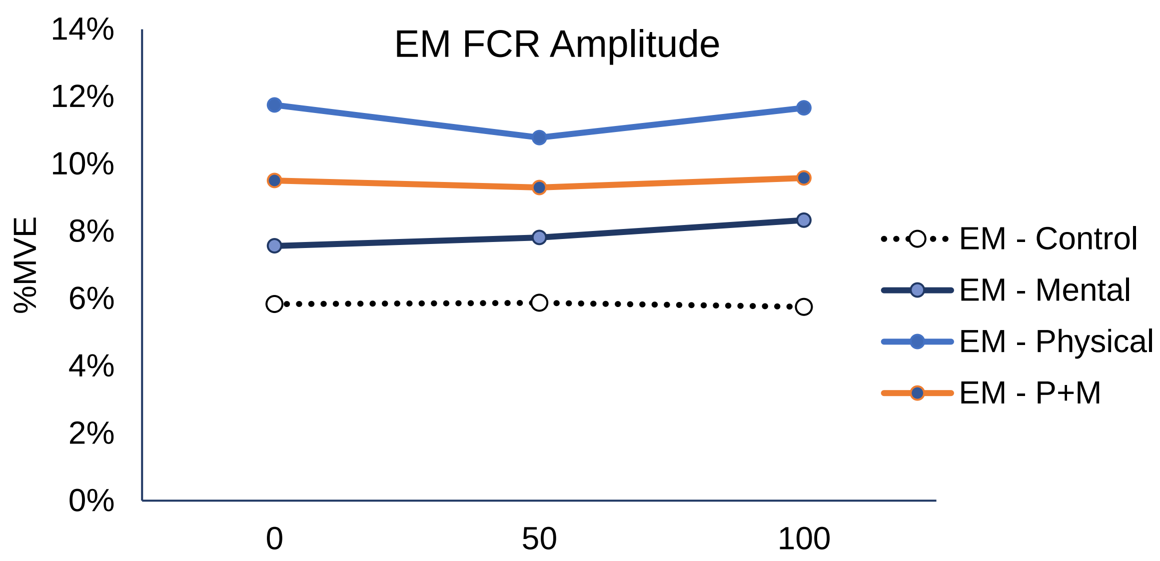

Figure 15: Mean aEMG of the FCR during the experimental manipulations. %MVE = percent of max voluntary excitation, EM=experimental manipulation, FCR = flexor carpi radialis, P+M = physical and mental.

3.2.2.6 MnPF

3.2.2.6.1 Endurance Trial MnPF

Descriptive statistics for endurance trial MnPF are shown, by condition, in Table 2. The mean participant MnPF for endurance trial 1 was 106±15.9 Hz for FCR and 123±20.5 Hz for ECR. The mean MnPF for endurance trial 2 was 108 ±15.7 Hz for FCR and 126±20.4 Hz for ECR.

The ECR displayed an increase in MnPF for the concurrent (7.5%) and control (2.2%) conditions between endurance trial 1 and 2 but almost no difference in the physical (-0.2%) and mental (-0.6%) conditions between endurance trial 1 and 2 (Figure 16). The FCR displayed an increase in MnPF for the physical (68%) and concurrent (3%) conditions but a decrease in the mental (-11%) and control (-15%) conditions between endurance trial 1 and 2 (Figure 17).

Overall, when looking at the ECR and FCR side by side, unexpectedly, there were few decreases in MnPF seen in the ECR in the mental and physical conditions. The largest change in

MnPF being during the concurrent condition that showed an increase of 7% in the ECR between the pre-post endurance trials with the FCR in the concurrent condition and mental conditions increasing similarly by 5% each respectively. The physical condition showed almost no difference in MnPF between the pre-post endurance trials (Figure 18).

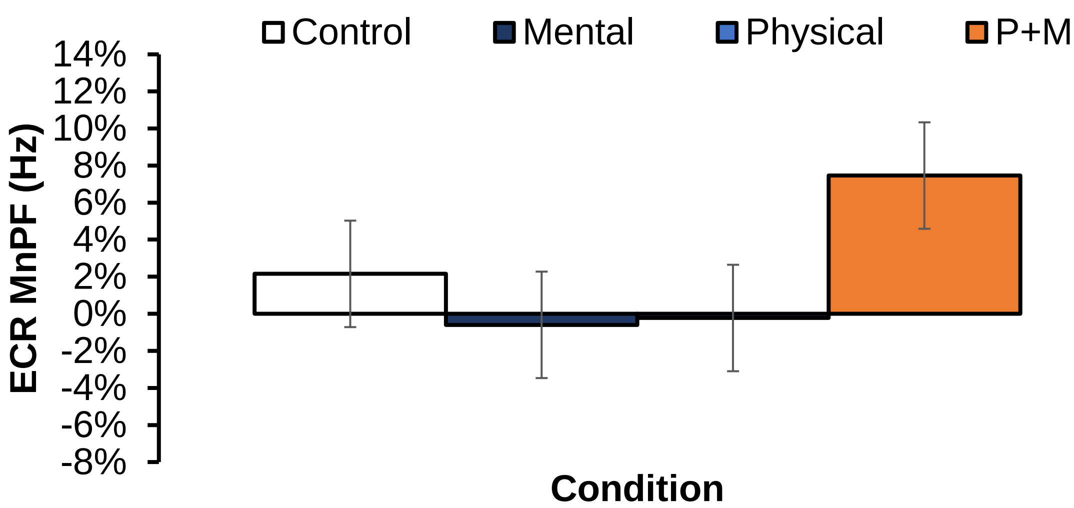

Figure 16: Percent change in MnPF between endurance trial 1 and endurance trial 2 the ECR. Error bars are presented in standard error. ECR = extensor carpi radialis, MnPF = mean power frequency, P+M = physical and mental

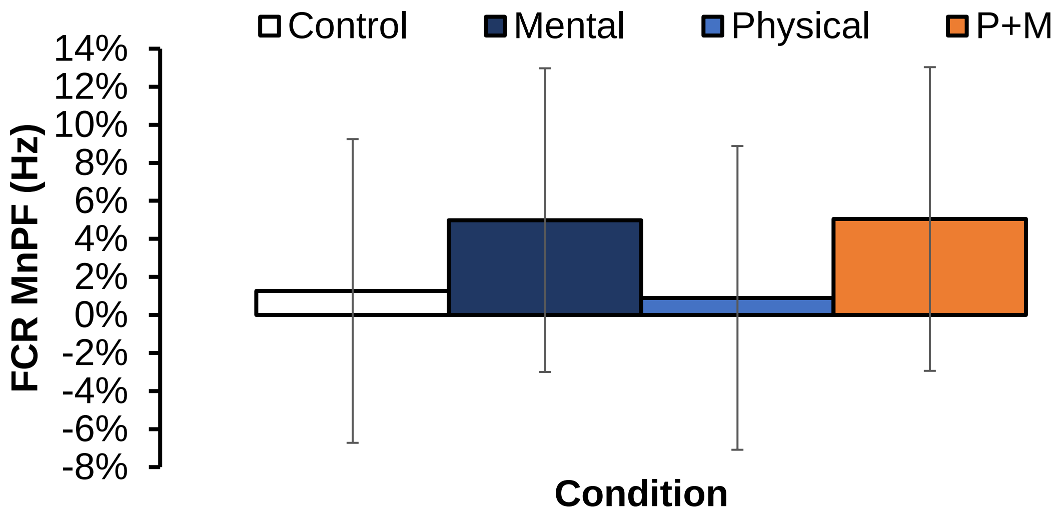

Figure 17: Percent change in MnPF between endurance trial 1 and endurance trial 2 for both the FCR and ECR. Error bars are presented in standard error. FCR = flexor carpi radialis, ECR = extensor carpi radialis, MnPF = mean power frequency, P+M = physical and mental

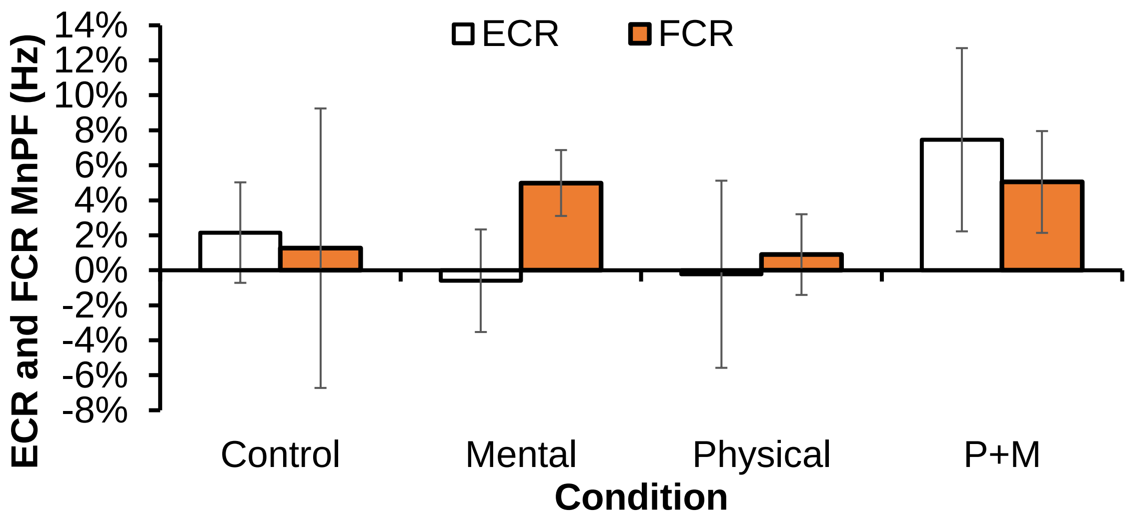

Figure 18: Percent change in MnPF between endurance trial 1 and endurance trial 2 for both the FCR and ECR. Error bars are presented in standard error. FCR = flexor carpi radialis, ECR = extensor carpi radialis, MnPF = mean power frequency, P+M = physical and mental.

3.2.2.6.2 Experimental Manipulation MnPF

Descriptive statistics for experimental manipulation MnPF are shown, by condition, in Table 2. Contrary to our hypothesis, during the experimental manipulation, MnPF increased for most conditions except for the physical condition where MnPF decreased substantially for the ECR muscle. The mean participant MnPF during the physical condition was observed to decrease throughout the experimental manipulation, decreasing from 157±10.4 Hz, to 146±7.45 Hz, to 140±9.52 Hz for the start, middle and end of the experimental manipulation respectively. The control, mental and concurrent conditions all increased in MnPF throughout the experimental manipulation (Figure 19).

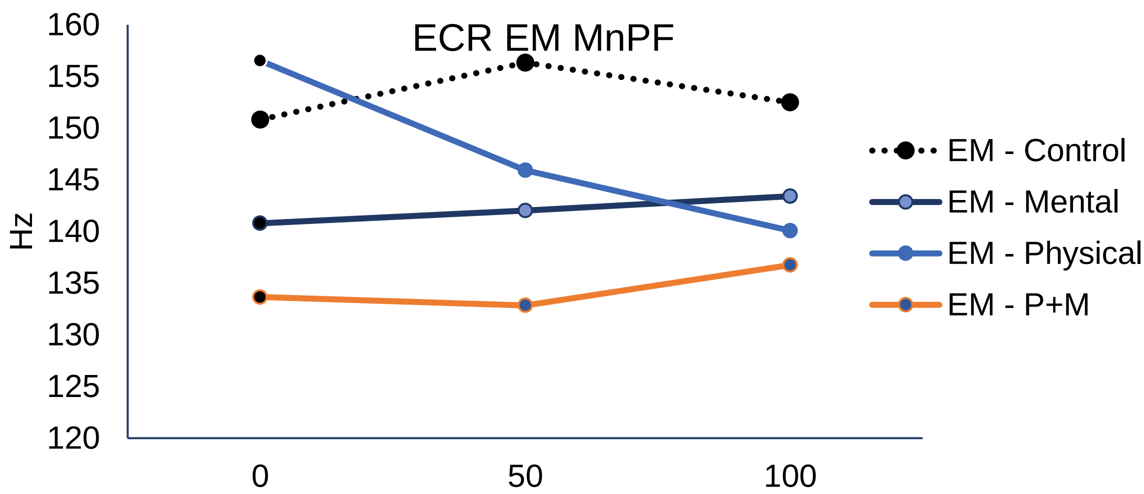

Figure 19: Mean MnPF of the ECR during the experimental manipulations. Error bars are presented in standard error. Hz = hertz, ECR = extensor carpi radialis, EM=experimental manipulation, MnPF = mean power frequency, P+M = physical and mental.

Contrary to our hypthesis, during the experimental manupulation MnPF increased slightly for the FCR muscle, essentially not changing throughout the EM. The mean particpoant MnPF during the concurrent condition showed minimal change, increasing from 94.0±20.3 Hz, to 95.5±21.7 Hz, then decreasing to 94.7±16.2 Hz for the start, middle and end of the experimental manipulation, respectively. The control, mental and physical conditions all increased in MnPF throughout the experimental manipulation (Figure 20).

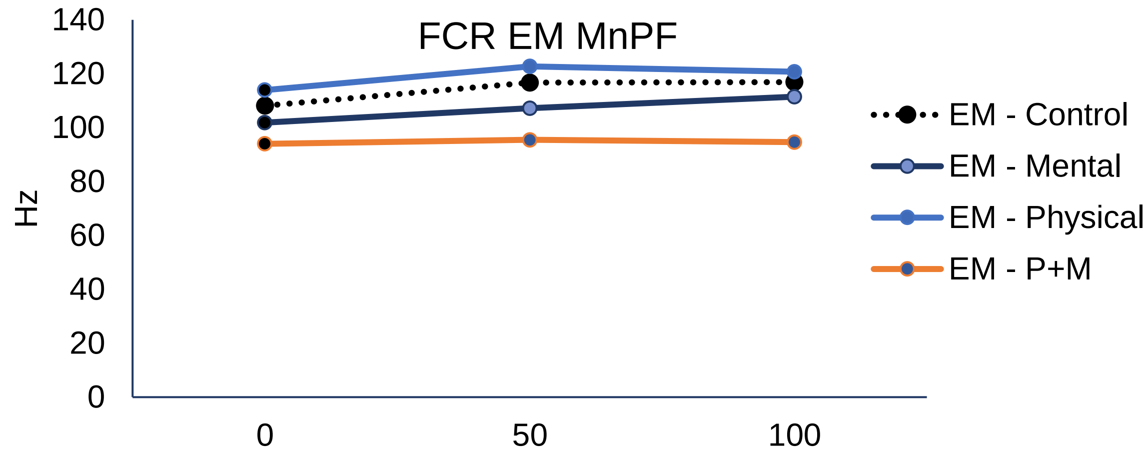

Figure 20: Mean MnPF of the FCR during the experimental manipulations. Error bars are presented in standard error. Hz = hertz, FCR = flexor carpi radialis, EM=experimental manipulation, MnPF = mean power frequency, P+M = physical and mental.

3.2.2.7 Primary Outcome Measures Raw Data Table

Table 2: Raw data points for all primary outcome measures.

Primary Outcome Measures						
	Time	**Control**	**Mental**	**Physical**	**P+M**	**Mean**
MVC	Baseline	451±56.5	464±49.2	455±69.6	449±59.6	454±53.3
	Pre	418±37.6	413±39.2	431±41.6	427±24.0	422±33.3
	Post	427±47.4	431±65.6	387±46.7	368±81.4	403±61.8
Endurance Time	Trial 1	56.8±20.6	54.8±21.2	61.2±22.6	53.7±20.5	56.6±21.2
	Trial 2	54.1±13.4	53.0±13.5	48.3±8.61	51.6±19.0	51.7±13.6
Force Variability	Trial 1	4.91±1.80	4.54±1.95	4.59±2.34	5.39±3.65	4.85±2.43
	Trial 2	4.62±2.14	5.35±1.99	4.99±2.36	3.94±1.77	4.72±2.06
Absolute Error	Trial 1	2.64±1.59	2.89±1.68	2.61±1.48	2.59±1.69	2.68±1.61
	Trial 2	2.76±1.41	2.56±1.47	2.39±1.54	2.28±1.35	2.50±1.44
FCR EMG amplitude	Trial 1	18.5±7.08	19.5±4.75	31.1±13.3	24.1±10.3	23.3±10.5
	Trial 2	19.7±9.77	19.6±3.44	39.2±18.9	24.9±10.9	25.9±14.3
ECR EMG amplitude	Trial 1	39.3±13.0	46.9±10.8	47.6±10.2	43.9±7.15	44.4±10.8
	Trial 2	41.1±12.3	45.8±13.9	49.2±8.63	44.9±9.44	45.3±11.4
FCR EMG MnPF	Trial 1	102±16.3	106±17.2	107±15.3	109±15.0	106±15.9
	Trial 2	109±18.9	105 ±16.6	105 ±8.78	114±16.1	108 ±15.7
ECR EMG MnPF	Trial 1	123±20.7	132±21.6	117±19.9	119±18.1	123±20.5
	Trial 2	124±27.4	129±19.0	123±17.2	128±17.5	126±20.4
(EM) FCR EMG Amplitude	EM Time - 0	5.83±2.79	7.56±4.26	11.75±5.53	9.51±5.14	8.66±4.43
	EM Time - 50	5.87±2.97	7.82±4.01	10.78±6.33	9.30±5.53	8.44±4.71
	EM Time – 100	5.76±2.85	8.33±3.81	11.67±7.66	9.58±5.68	8.83±5.00
(EM) ECR EMG Amplitude	EM Time - 0	14.0±4.19	12.8±2.41	13.4±2.55	13.0±3.56	13.3±3.18
	EM Time - 50	21.0±18.6	15.3±2.27	17.0±7.7	15.0±4.54	17.0±8.26
	EM Time - 100	15.1±3.24	14.2±1.96	18.0±6.02	14.2±4.07	15.3±3.82

(EM) FCR EMG MnPF	EM Time - 0	108±31.8	102±36.9	114±20.5	94.0±20.3	104±27.4
	EM Time - 50	116.7±39.6	107±42.7	123±11.6	95.5±21.7	111±28.9
	EM Time - 100	117±37.0	111±50.6	121±18.2	94.7±16.2	111±30.5
(EM) ECR EMG MnPF	EM Time - 0	151±31.4	141±30.4	157±10.4	134±23.2	145±23.8
	EM Time - 50	156±39.1	142±28.9	146±7.45	133±19.1	144±23.6
	EM Time - 100	152±34.5	143±36.5	140±9.52	137±22.8	143±25.8

3.2.3 Secondary Psychological Measures

3.2.3.1 RPE

Descriptive statistics for RPE ratings are shown, by condition, in Table 3. The mean participant RPE ratings are 5.94±3.18 and 6.53±3.06 for endurance trials 1 and 2 respectively in the control condition. In the mental condition, RPE ratings are 5.50±4.12 and 6.13±4.05 for endurance trials 1 and 2, respectively. In the physical condition, RPE ratings are 5.63±3.94 and 6.50±3.51 for endurance trials 1 and 2, respectively. In the concurrent condition, RPE ratings are 6.75±2.63 and 7.00±2.94 for endurance trials 1 and 2, respectively. Additionally, the mean participant RPE ratings across all conditions for endurance trial 1 (pre) was 5.94±3.18 and the mean RPE ratings for endurance trial 2 (post) was 6.53±3.06.

As expected, RPE values in the post-manipulation endurance trial follow a similar trend across all conditions, with participants reporting higher RPE following endurance trial 2 when compared to endurance trial 1. As seen in Figure 21, participants in the concurrent condition reported the highest post-manipulation RPE values, and the mental condition reported the lowest post-manipulation values out of all conditions (including the control condition).

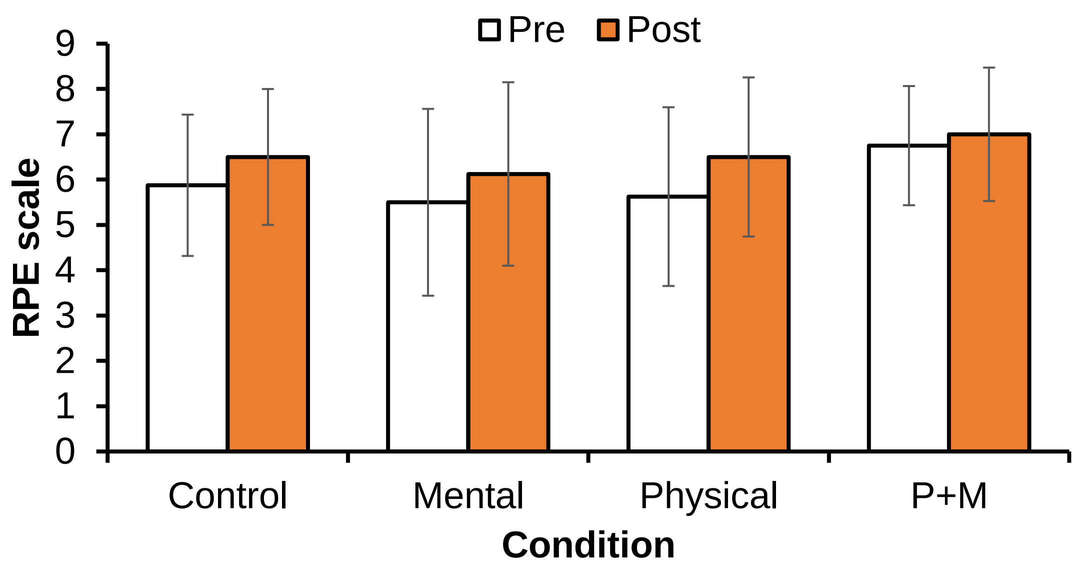

Figure 21: RPE ratings after endurance trial 1 and 2 respectively for each condition. Error bars are presented in standard error. RPE = Rated perceived exertion, P+M = physical and mental.

3.2.3.2 FS

Descriptive statistics for FS ratings are shown, by condition, in Table 3. The mean Feeling Scale values across all measurements were highest in the control (2.60±1.47) condition and lowest in the concurrent (1.54±2.76) condition. Between the experimental manipulations, the physical (1.93±2.10) condition reported the highest FS values, and the concurrent condition reported the lowest FS values, however the concurrent condition only reported slightly lower FS values than the mental (1.54±2.17) condition.

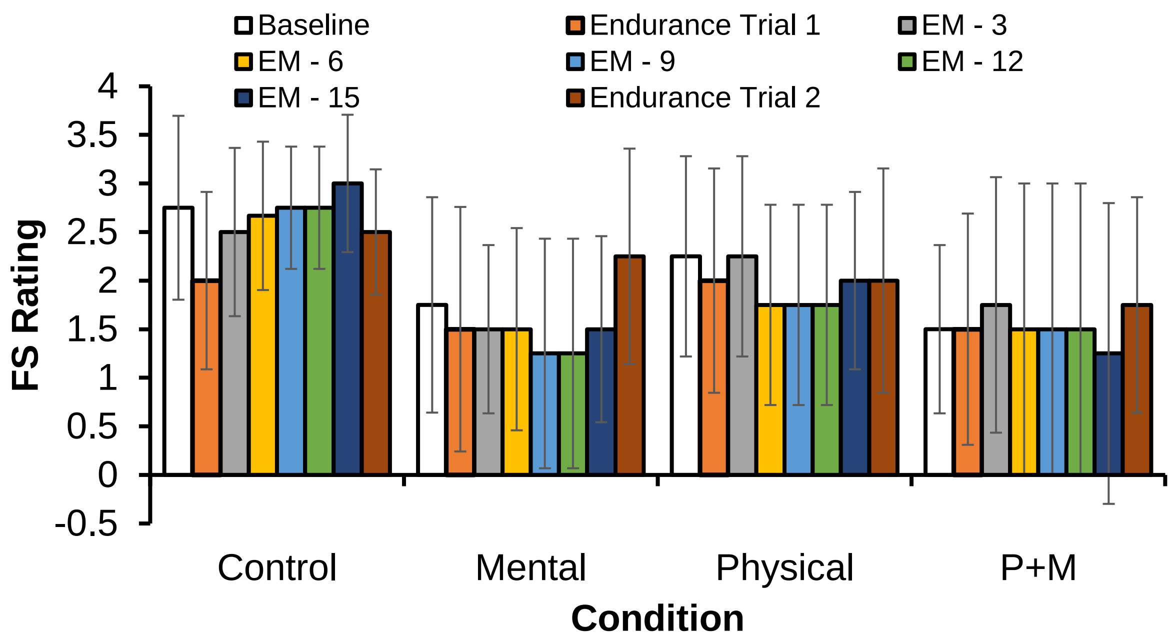

Figure 22: FS ratings throughout a session for each condition. Error bars are presented in standard error. FS = feeling scale, EM=experimental manipulation followed by time point in minutes, P+M = physical and mental.

3.2.3.3 IMI

Descriptive statistics for IMI ratings are shown, by condition, in Table 3. The mean participant IMI ratings for endurance trial 1 are 6.09±0.83 and the mean IMI ratings for endurance trial 2 are 6.01±0.83.

Motivation between endurance trial 1 and endurance trial 2 was similar between conditions with motivation decreasing prior to endurance trial 2 in the control, physical and concurrent conditions, however motivation increased prior to endurance trial 2 in the mental fatigue condition. Overall, motivation stayed similar from endurance trial 1 to endurance trial 2 between conditions.

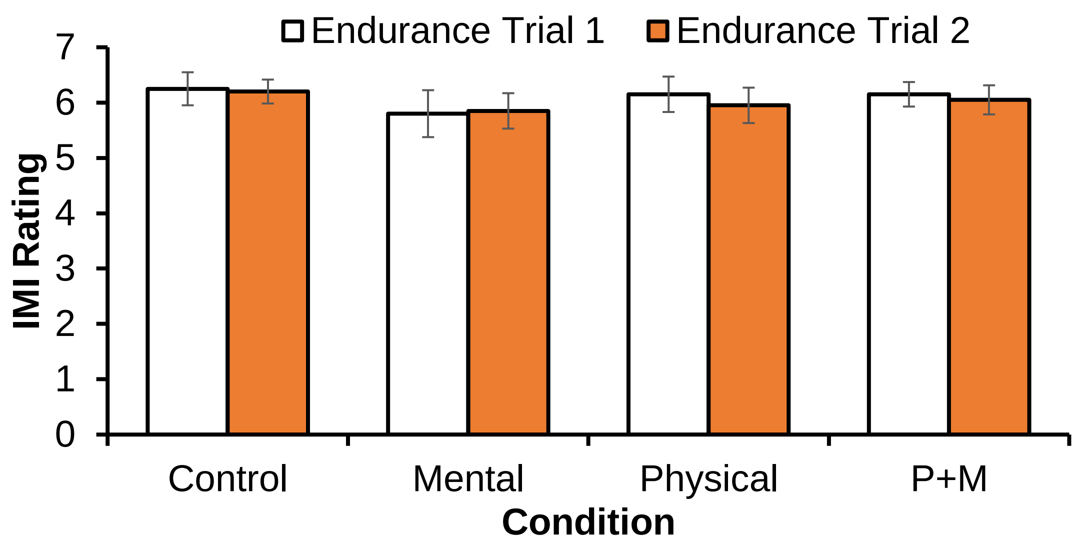

Figure 23: Mean IMI ratings before endurance trial 1 and 2 respectively for each condition. Error bars are presented in standard error. IMI = intrinsic motivation inventory, P+M = physical and mental.

3.2.3.4 TSE

Descriptive statistics for TSE ratings are shown, by condition, in Table 3. The mean participant TSE ratings are 4.03±0.54 in the control condition, 4.31±1.22 in the mental condition, 4.19±0.80 in the physical condition and 4.44±0.79 in the concurrent condition.

Task self-efficacy appeared to have little to no change throughout all conditions. The control condition reported the lowest TSE ratings, and the concurrent condition reported the highest TSE ratings however the difference between these conditions is minimal.

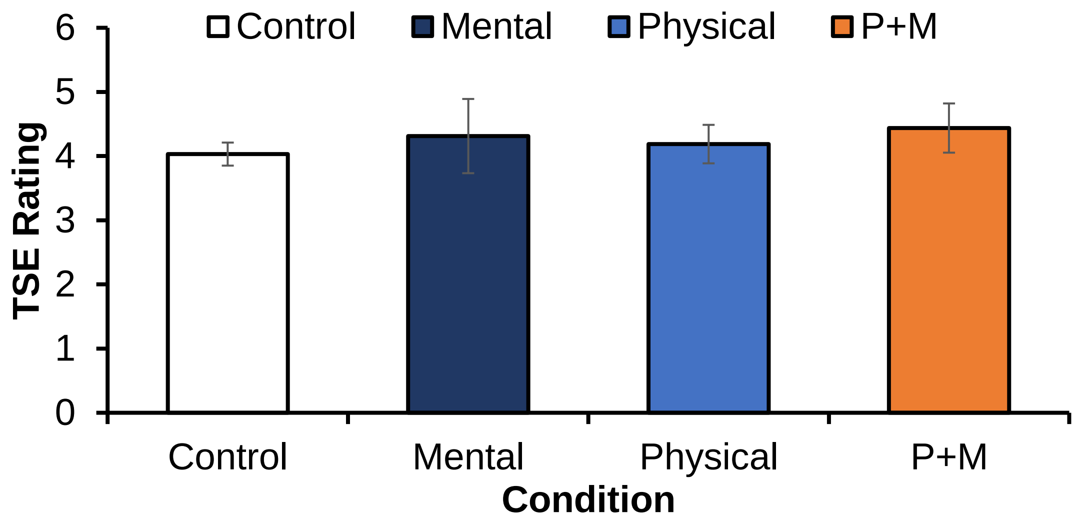

Figure 24: Mean TSE ratings for each condition. Error bars are presented in standard error. TSE = task self-efficacy, P+M = physical and mental.

3.2.3.5 Secondary Psychological Measures Raw Data Table

Table 3: Raw data points for all secondary outcome measures.

Secondary Psychological Measures						
	Time	Control	Mental	Physical	P+M	Mean
RPE	Trial 1	5.88±3.12	5.50±4.12	5.63±3.94	6.75±2.63	5.94±3.18
	Trial 2	6.50±3.00	6.13±4.05	6.50±3.51	7.00±2.94	6.53±3.06
IMI	Pre EM	6.25±0.77	5.80±1.00	6.15±0.87	6.5±0.77	6.09±0.83
	Post EM	6.20±0.71	5.85±0.93	5.95±0.96	6.05±0.87	6.01±0.83
PMF	Baseline	13.1±14.0	12.1±13.2	17.8±21.0	24.1±19.6	16.8±16.2
	Pre EM	14.0±14.6	15.4±12.5	18.3±20.3	21.1±14.2	17.2±14.3
	EM 3	13.4±10.6	29.4±22.5	22.3±22.4	28.5±11.8	23.4±17.2
	EM 6	11.5±9.47	34.3±23.8	21.6±22.2	37.8±11.6	26.3±19.3
	EM 9	11.1±8.87	40.4±23.3	23.8±24.2	43.3±13.3	29.6±21.4
	EM 12	11.8±8.85	47.9±24.6	24.6±23.5	47.5±19.4	32.9±24.0
	EM 15	11.3±8.80	50.3±26.3	26.3±27.6	49.6±22.8	34.3±26.5
	Post EM	13.1±10.0	34.8±25.0	24.4±25.5	35.4±21.1	26.9±21.3
PPF	Baseline	16.5±14.3	15.0±16.1	22.1±17.8	24.1±13.2	19.4±14.3
	Pre EM	20.4±11.3	30.0±18.2	35.6±15.7	35.9±6.18	30.5±13.8
	EM 3	17.0±7.44	26.9±17.2	29.9±16.7	27.9±10.6	25.4±13.2
	EM 6	16.4±10.2	26.5±19.8	32.9±15.2	36.0±12.8	27.9±15.4
	EM 9	14.0±9.06	32.3±22.5	32.0±18.4	36.0±14.9	28.6±17.5
	EM 12	12.6±8.10	29.9±23.6	31.1±16.1	36.1±19.3	27.4±18.3
	EM 15	12.8±8.17	29.8±23.1	38.6±24.0	40.6±27.5	30.4±22.7
	Post EM	28.4±14.0	41.0±26.8	49.3±22.7	48.6±19.3	41.8±20.9

FS	Baseline	2.75±1.89	1.75±2.22	2.25±2.06	1.50±1.73	2.06±1.84
	Pre EM	2.00±1.83	1.50±2.52	2.00±2.31	1.50±2.38	1.75±2.05
	EM 3	2.50±1.73	1.50±1.73	2.25±2.06	1.75±2.63	2.00±1.90
	EM 6	2.67±1.53	1.50±2.08	1.75±2.06	1.50±3.00	1.80±2.08
	EM 9	2.75±1.26	1.25±2.36	1.75±2.06	1.50±3.00	1.81±2.10
	EM 12	2.75±1.26	1.25±2.36	1.75±2.06	1.50±3.00	1.81±2.10
	EM 15	3.00±1.41	1.50±1.91	2.00±1.83	1.25±3.10	1.94±2.05
	Post EM	2.50±1.29	2.25±2.22	2.00±2.31	1.75±2.22	2.13±1.86
TSE		4.03±0.54	4.31±1.22	4.19±0.80	4.44±0.79	4.24±0.84

Chapter 4

4.1 - Discussion

Due to substantial delays caused by the COVID-19 pandemic, this thesis focused on a smaller-scale pilot study to initially examine this research question and evaluate the proposed methods of this novel experimental design.

The present study investigated the independent and interactive carryover effects of physical and mental fatigue on upper limb strength, endurance, muscle activity, force fluctuation and performance error after performing either a mental fatigue, neuromuscular fatigue, or concurrent mental and physical fatigue protocol, in addition to a control condition. It was hypothesized that both mental fatigue and physical fatigue would have a negative impact on physical performance, but the combination of mental and neuromuscular fatigue would yield the greatest detrimental effects on physical performance as compared to mental and muscle fatigue independently, in addition to the control condition.

As such, the results of this thesis are derived from a small sample size (n=4), so interpretation of the findings must be viewed in light of this. However, several initial findings emerged to encourage future research, and allowed for insight on several experimental modifications that can be considered for the future larger-scale study.

4.1.1 Strength of Experimental Manipulations

An initial important finding is that the fatigue manipulations appeared to induce substantial levels of mental and physical fatigue. Specifically, as expected, PMF scales showed a large increase in PMF ratings during the mental and concurrent conditions, a small increase in the physical condition, and ratings stayed similar throughout the control condition. The large increases in PMF ratings during the mental and concurrent conditions indicate that the participants perceived the arithmetic task to be mentally fatiguing. Additionally, as expected, PPF scales showed a large increase in PPF ratings during the physical and concurrent conditions, a larger increase in the mental condition compared to the control, and a slight increase in the control condition. The large increases in PPF ratings during the physical and concurrent conditions indicate that participants perceived the physical fatigue manipulation task to be physically fatiguing. During the concurrent condition, PMF ratings were observed to be higher than the control, mental and physical conditions and PPF ratings in the concurrent condition were observed to be higher than both the mental and control conditions. The PMF ratings are consistent with previous research that has used a similar VAS to the one used in this pilot study. Previous research has found that a high cognitive control condition produced significantly more mental fatigue over the course of an experimental manipulation designed to induce mental fatigue when compared to a control condition (Brown and Bray, 2017). Similarly, the mental fatigue and concurrent conditions in this pilot study also had the highest ratings of perceived mental fatigue.

Another important finding was that RPE scores were consistent throughout the conditions. Participants reported similar RPE ratings between endurance trials 1 and 2, which indicates that participants were exerting the same amount of effort in each of the endurance trials, regardless of the condition they were completing. The RPE scores for endurance trial 2 follow a similar trend across all conditions where they are all slightly higher than endurance trial 1, indicating there was a slight increase in perception of effort. When compared to the change in endurance times between endurance trial 1 and 2, all conditions reported similar RPE ratings however, the concurrent and physical fatigue conditions showed greater reductions in endurance time when compared to the mental fatigue and control conditions. Based on the models proposed by Marcora and colleagues (2009) and Pageaux (2016) (see section 2.3.1.2), participants reached their perceived level of tolerable effort sooner following the concurrent and physical fatigue condition. According to the model explained by Pageaux (2016), the slight increase in perceived effort could be generated by central or peripheral interference (such as increased muscle pain or metabolite buildup) that makes participants perceive the task to be more difficult. These findings are consistent with a previous meta-analysis that found tasks that require participants to sustain constant force production resulted in participants reaching their perceived tolerable limit sooner than if they were not mentally fatigued (Brown et al., 2020). Additionally, previous research has also found that RPE ratings are similar between conditions such as the study by Graham and Bray (2015) that reported ratings of perceived exertion were similar between similar manipulations (incongruent and congruent Stroop Task groups) for both handgrip endurance trials. The participants in our study also reported higher RPE ratings after the post-EM endurance trial when compared to RPE recorded in the pre-EM endurance trial however, the mental fatigue condition did not have higher RPE ratings when compared to the control condition.

Feeling Scale values indicated that participants felt the best during the control condition and felt the worst during the concurrent condition. This was an expected finding, as in the control condition, participants were not being fatigued by completing the arithmetic test or a handgrip fatiguing task while in the concurrent condition participants are completing both the arithmetic test and the handgrip fatiguing task at the same time. These findings also align with the previous research suggesting that cognitive demanding tasks can lead to shifts in negative affect or feeling states (Inzlicht et al 2014; Inzlicht et al 2015).

The psychological state scales also provide encouraging results regarding the suitability of the experimental protocols. The pre and post IMI scales showed that participants had similar motivation to perform both endurance trials, meaning participants were equally motivated to complete and do well on the second endurance trial when compared to the first endurance trial. These results are consistent with the study previously mentioned by Marcora and colleagues (2009) that found motivation scores related to the physical task were unaffected by prior cognitive activity. Additionally, the task self-efficacy of participants in the present study was not affected by the experimental manipulations as the scores were similar between all conditions. In general, participants were equally confident in their ability to last as long as the first endurance trial. Since endurance times did decrease the most during the mental, physical and concurrent conditions, this is another indicator that the mental fatiguing task and the physical fatiguing tasks were truly fatiguing participants, as they thought they could go as long as the first endurance trial (and were motivated to do so), but after completing the experimental manipulation, they were not able to. The TSE score during the control condition also indicates that participants thought they could go as long on the second endurance trial when compared to the first endurance trial and they did come closer to lasting as long as their first endurance trial compared to the experimental conditions. Although the TSE scores were similar between conditions, the control condition did have the lowest TSE score which is not consistent with past research. The study by Graham and Bray (2015) investigated the role of task self-efficacy between self-control and physical endurance. Participants in this study completed two handgrip endurance trials at 50% MVC for as long as possible and gave feedback on various manipulation checks. TSE was measured before the second endurance trial and the study reported lower self-efficacy to perform the second endurance trial in the mental fatigue group (Stroop task) when compared to the control group (Graham and Bray, 2015). In this pilot study, the control condition reported the lowest TSE scores which is contradictory to the findings of Graham and Bray however when considering the small sample size of this study and the minimal differences of TSE between conditions, this result is still inconclusive until a larger participant pool is sampled.

4.1.2 Initial Experimental Findings

Endurance time decreased for all conditions with the control condition having the least amount of time decrease between endurance trials. The mental condition had a small decrease in endurance time between endurance trials while the physical and concurrent conditions had similar decreases in endurance time. This suggests that the mental condition had less of an effect on endurance time when compared the concurrent and physical conditions. When compared to the control condition, endurance time in the mental fatigue condition was slightly more negatively affected by the arithmetic test which may suggest that the mental condition has little to no effect on endurance time when compared to the concurrent and physical fatigue conditions. However, the decrease in endurance time in the mental condition could be an indicator of central fatigue as a previous study found that central fatigue can be induced by a mentally fatiguing task and central fatigue can negatively affect physical performance (Bray et al., 2008; Kennedy et al., 2013). The decreases in endurance time in the physical and concurrent conditions are likely caused by peripheral fatigue which was induced by the handgrip fatiguing protocol (Enoka and Duchateau, 2008; Gandevia, 2001). In addition to this, when compared to the RPE scores, the reduced endurance times may suggest that participants reached their tolerable physical limit faster but perceived themselves to be exerting around the same amount. Mehta and Agnew (2012) investigated the effects of physical workload and concurrent workload (physical and mental) on muscle endurance, fatigue, and strength recovery. The endurance test experimental manipulation had a similar protocol to the experimental manipulation for the physical and concurrent conditions in this pilot study. In Mehta & Agnew (2012), participants performed intermittent exertions with 15 seconds of exertions followed by 15 seconds of rest however participants in that study exerted at 15, 35, or 55% MVC until failure. The concurrent mental and physical condition produced a decline in concurrent endurance time at 35% MVC and 55% MVC however the decline at 55% MVC was minimal between the concurrent and physical only conditions (Mehta and Agnew, 2012). The endurance trial in this pilot study was performed at 50% MVC and also saw minimal differences between the physical only and concurrent fatigue conditions. Although this pilot study requires more data, it is important to acknowledge that this study extends previous research as it investigated the carryover effects of a concurrent mental and physical fatigue manipulation on physical endurance.

MVCs increased from pre to post experimental manipulation for the control and mental condition; however, MVCs decreased in the physical condition and decreased further in the concurrent condition. This may suggest that there was an additive effect on MVCs during the concurrent condition caused by the mental arithmetic task which caused the MVCs in that condition to be lower by inducing mental fatigue in addition to the peripheral fatigue induced by the handgrip fatigue protocol, which is consistent with some previous research. Mehta and Agnew (2012) investigated the effects of physical and concurrent physical and mental workload on muscle endurance, fatigue, and strength recovery. The study observed that the concurrent condition had greater strength decline between pre-post EM when compared to the physical fatigue only group (Mehta and Agnew, 2012). This observation is consistent with the results in this pilot study as the concurrent mental and physical fatigue also had a greater decrease in MVC force production between pre-post EM in the concurrent condition when compared to the physical only condition. The mental fatigue condition displayed an increase in MVC force production from pre to post MVC. The lack of mental fatigue findings in this pilot study aligns with the meta-analysis by Brown and colleagues (2020) which suggested mental fatigue does not affect maximal anaerobic or strength-based task performance, such as the handgrip MVCs in this thesis.

Force variability decreased in the concurrent condition between endurance trial 1 and 2 while the mental and physical conditions led to an increase in force variability. This suggests that after completing the concurrent condition, participants were less variable in their force output during endurance trials when compared to the mental, physical or control conditions. This is consistent with the force fluctuations Mehta and Agnew (2011) observed in their study where participants exerted three sets of 10-second isometric MVCs at 5%, 25%, 45%, 65% and 85% MVCs. They found that force fluctuations were higher in their concurrent physical and mental condition at 65% MVC and 85% MVC when compared to their physical only condition but force fluctuations were lower in concurrent condition when compared to the physical only condition at 25% MVC and 45% MVC, suggesting that motor performance improved during these MVC levels with the additional mental task (Mehta and Agnew, 2011). As stated previously, participants in our study were required to exert at 50% MVC during an endurance trial. While participants in the Mehta and Agnew (2011) study performed MVCs at multiple exertion levels, it can still be noted that at 45% MVC force fluctuations were lower in their concurrent condition and motor performance improved. Similarly, force fluctuations were lower in the concurrent condition in our study for a similar exertion level at 50% MVC.

Performance error decreased in the physical and concurrent conditions between endurance trial 1 and 2 while performance error increased in the mental and control conditions. This means that in the physical and concurrent conditions, participants deviated less from the target force (50% MVC) and in the mental and control conditions, participants deviated more from the target force during the endurance trials. Similar to the above with regards to force variability, performing the concurrent task may make participants more accurate in staying close to the target MVC when compared to the other conditions.

In comparison to the endurance time and MVC findings, the EMG and MnPF data appeared to be most affected by the small sample size due to the large intra- and inter-participant variability that was observed. Between pre-post endurance trials for the ECR, EMG amplitude increased considerably in the physical condition and increased slightly in the mental and concurrent conditions; however, EMG amplitude decreased considerably in the control condition. Between pre-post endurance trials for the FCR, EMG amplitude also increased considerably in the physical condition and increased slightly in the concurrent condition; however, EMG amplitude decreased in the control and mental conditions. Overall, EMG amplitude during the endurance trial increased considerably in the physical condition and increased slightly in the concurrent condition; however, EMG amplitude decreased in the control and mental conditions. The results observed for the mental condition are not consistent with the results found by Bray and colleagues (2008) that investigated the effects of self-regulatory strength depletion on an isometric handgrip task and investigated the effect of depletion on EMG activity during an endurance task. The study had a control (reading colour words) and a cognitive depletion (Stroop test) group that completed a pre and post endurance trial with the cognitive task between the two endurance trials (Bray et al., 2008). Participants in the cognitive depletion group had a greater increase in EMG amplitude during their second endurance trial when compared to the control, however the control group also had an increase in EMG amplitude. The decrease in EMG amplitude during the control and mental conditions was unexpected but may be an artifact due to the small sample size. This is especially true for EMG amplitude, which is often less reliable within and between testing days in comparison to variables such as MVC and endurance time (Al-Zahrani et al., 2009). As seen in the PPF scales, all conditions did produce increases in PPF ratings, which means the control and mental conditions may have perceived themselves to be fatigued and gave up prematurely. EMG amplitude during the experimental manipulation found that compared to the control condition, EMG amplitude increased in all experimental conditions for the ECR. However, for the FCR EMG amplitude decreased in all experimental conditions compared to the control condition. Shortz and Mehta (2017) investigated the effects of cognitive challenges on handgrip fatigue with aging. There were three experimental conditions: control (handgrip fatigue only), cognitive fatigue (Stroop test and 1-Back test) prior to handgrip fatigue, and concurrent cognitive (arithmetic task) and handgrip fatigue. During the handgrip fatiguing protocols, participants were instructed to intermittently exert at 30% MVC for 15 seconds and rest for 15 seconds until exhaustion. The study found that muscle activity for the ECR and FCR increased over time for all three conditions in both age groups (Shortz and Mehta, 2017). Although this pilot study also observed increases in muscle activity for the ECR, the results are contradictory for the FCR as muscle activity was observed to decrease for the concurrent P+M and mental conditions however muscle activity increased minimally for the control and physical conditions for the FCR muscle. Similar to the observation reported in this pilot study, FCR muscle activity was lower than ECR muscle activity (as seen in the experimental manipulation) which may suggest that the FCR is not a major contributor to force production during handgrip exercises.

Unexpectedly, MnPF increased in all conditions between the two endurance trials, with the concurrent condition displaying the greatest increase in MnPF compared to all other conditions and the physical condition displaying almost no difference in MnPF between endurance trials. Between pre-post endurance trials for the ECR, MnPF increased considerably in the concurrent condition and also increased in the control condition; however, MnPF decreased slightly in the mental condition and there was almost no difference in MnPF in the physical condition. Between pre-post endurance trials for the FCR, MnPF increased similarly and considerably in the concurrent and mental conditions and also increased in the control and physical conditions. MnPF during the experimental manipulation for the ECR decreased in all experimental conditions when compared to the control condition. A similar trend was seen for the FCR during the experimental manipulation with the exception of the physical condition increasing in MnPF compared to the control condition. Mehta and Agnew (2012) observed a decrease in MnPF during their physical fatigue conditions and found no increase in MnPF during their mental fatigue conditions. All the experimental manipulations increasing in MnPF in the endurance trials may again be an artifact due to the small sample size of this pilot study.

4.1.3 Alterations for Full Study

As the examination of the carryover effects of concurrent mental and neuromuscular fatigue protocols on physical performance are limited, this study is one of the first to examine this phenomenon in a within-subject repeated measures design. As such, this study required adoption of several assumptions and novel experimental protocols, which made this topic well suited for an in-depth pilot analysis. Based on conducting the experiment on a limited sample of participants, and initially examining the data, it is apparent that several changes can be considered in order to improve the larger-scale version of this study.

4.1.3.1 Stability of Baseline Measures

This study relied heavily on comparisons preceding and following four experimental conditions. The study originally sought to compare post-manipulation measurements (e.g., endurance time, MVC, performance error, etc.) against baseline values that were collected that same day. However, this approach made the results quite sensitive to intra-trial variability within each participant. To mitigate this effect in this pilot analysis, we established a common 'baseline' measurement for primary outcome variables using the mean of the 'pre' conditions, from all four days of testing. This procedure stabilized the pre-post comparisons, as any single condition was not as affected if, for example, a participant had a 'bad grip' on their initial endurance trial, or some other factor that resulted in an abnormal measurement. Furthermore, by conducting a ‘pre’ endurance trial on every day, participants were subjected to an extreme fatigue exposure before conducting any of the experimental manipulations (see Figure 8).

An alternative protocol, that may alleviate some of these limitations, could be having participants complete two or three baseline endurance trials, separated by adequate rest, during an initial familiarization session, and only using an endurance trial during the post-manipulation measurement sessions and then comparing that endurance trial across the four different conditions (mental, physical, concurrent, control). With this protocol, participants will come in on day one to be familiarized with the task and equipment. Then participants are randomized into either the mental, physical, or concurrent fatigue or control protocol on day 2-5. On the experimental days, participants complete the baseline MVCs, pre-EM MVC, the experimental manipulation, post-EM MVC and then one endurance trial. This can be observed in the meta-analysis by Brown and colleagues (2020) that investigated the negative carryover effects of prior cognitive exertion on different types of physical tasks. In their meta-analysis, they compared between and within-subject designs of over 30 different studies, indicating that within-subject study designs are common in mental fatigue research. There are two papers that provide a good model for this approach. Penna and colleagues (2018) had sixteen swimmers perform a 1500-meter time trial on two separate sessions with the sessions randomly being allocated as a control (watching a neutral video) or mental fatigue (complete a 30-minute Stroop task) group. During each experimental session, participants first completed a VAS to assess mental fatigue and then completed either the mental fatigue or control condition. Immediately after the condition, mental fatigue, mental effort and motivation was assessed using VAS and heart rate was measured for a total of 5 minutes. Following the measurements, participants completed the 1500-meter time trial and mental effort measurements, and heart rate were recorded again after the time trial. The results showed that participants reported higher ratings of mental fatigue and mental effort after completing the Stroop task when compared to the control condition, however no differences in motivation were observed. Mental fatigue increased the time to complete the swimming time trial by 1.2% and differences were observed for ratings of perceived exertion or heart rate variability. These results indicate that mental fatigue affects the ability to complete the swimming time trial without changing heart variability (Penna et al., 2018). The second study that utilized a similar protocol as the proposed alternative protocol above is the study by Marcora and colleagues (2009) that had participants come in on day one for a preliminary exercise test that was completed until exhaustion to measure VO_2 peak and peak power and gave RPE ratings. During the second visit, participants were given a psychological questionnaire to assess mood and motivation, had a blood sample taken from the ear lobe (to measure lactate concentration), and then completed either the experimental (mental fatigue) or control (watching neutral mood videos) conditions. After completing one of the conditions, participants completed the psychological questionnaire again, gave another blood sample, and completed a motivation questionnaire for the upcoming task. Finally, participants then completed a high intensity constant-power cycling test at 80% peak power until exhaustion with physiological and perceptual responses (oxygen uptake, blood sample, cardiac output) were measured throughout the cycling test. On the third visit, the same procedures were followed but they completed the condition that was opposite to what they completed during the second visit. The mood questionnaire revealed the mental fatigue contributed to reduced time to exhaustion when compared to the control condition and physiological responses were unaffected by the intense exercise. Additionally, motivation was reported to be unaffected by the prior cognitive activity and perception of effort was significantly higher in the mental fatigue condition when compared to the control condition. These studies utilized a similar protocol to the alternative protocol proposed and may alleviate any potential fatigue carrying over from a “pre” endurance trial performed on the same day. Additionally, when looking at the performance error for endurance trial 1, performance error decreased for some participants for each subsequent session which may indicate that there is a learning effect caused by the amount of exposure each participant had with the endurance task. Within this proposed approach, a more substantial familiarization component could be added to day 1, which could also help alleviate any concerns around a learning effect as participants will be exposed to the endurance task once every session instead of twice every session (see Figure 10).

During the experimental manipulation, participants intermittently exerted at 15.3% MVC in the concurrent and physical conditions to induce physical fatigue. As mentioned earlier, this exposure level (i.e., 15.3% MVC at a duty cycle of 50%) is considered the ergonomic upper limit for this type of repetitive work and was expected to elicit an initial fatigue response (Potvin, 2012; Abdel-Malek et al., 2020). PPF ratings indicated that this protocol was fatiguing participants; however, it is possible that the study could implement an exertion level higher than 15.3% MVC. Previous studies have used various exertion levels such as 15%, 35% and 55% MVC and as expected, found that as the exertion level increased, endurance times and strength decreased (Mehta and Agnew, 2012).

As mentioned earlier, Penna et al (2018) had one physical trial (swimming time trial) after each condition (mental or control) and compared the time differences of the trial between the conditions. In relation to the proposed modification to the future study, we will have one endurance trial after each condition and compare the differences of the endurance trial between conditions and a baseline endurance trial (average of 2 or 3 baseline trials with adequate rest) conducted on the familiarization day. This can be beneficial to incorporate into the future full study since it will reduce the time of each session and more importantly, it can reduce the risk of the arm still being fatigued from the pre-EM endurance trial. This can also be seen in the control endurance trial of this study where there is minimal change in endurance time between pre-post endurance trials, indicating that the 15 minutes of rest participants did during the EM allowed participants to recover adequately. A visual representation of the proposed modification can be viewed in Figure 25.

4.1.3.1.1 Modified Procedure

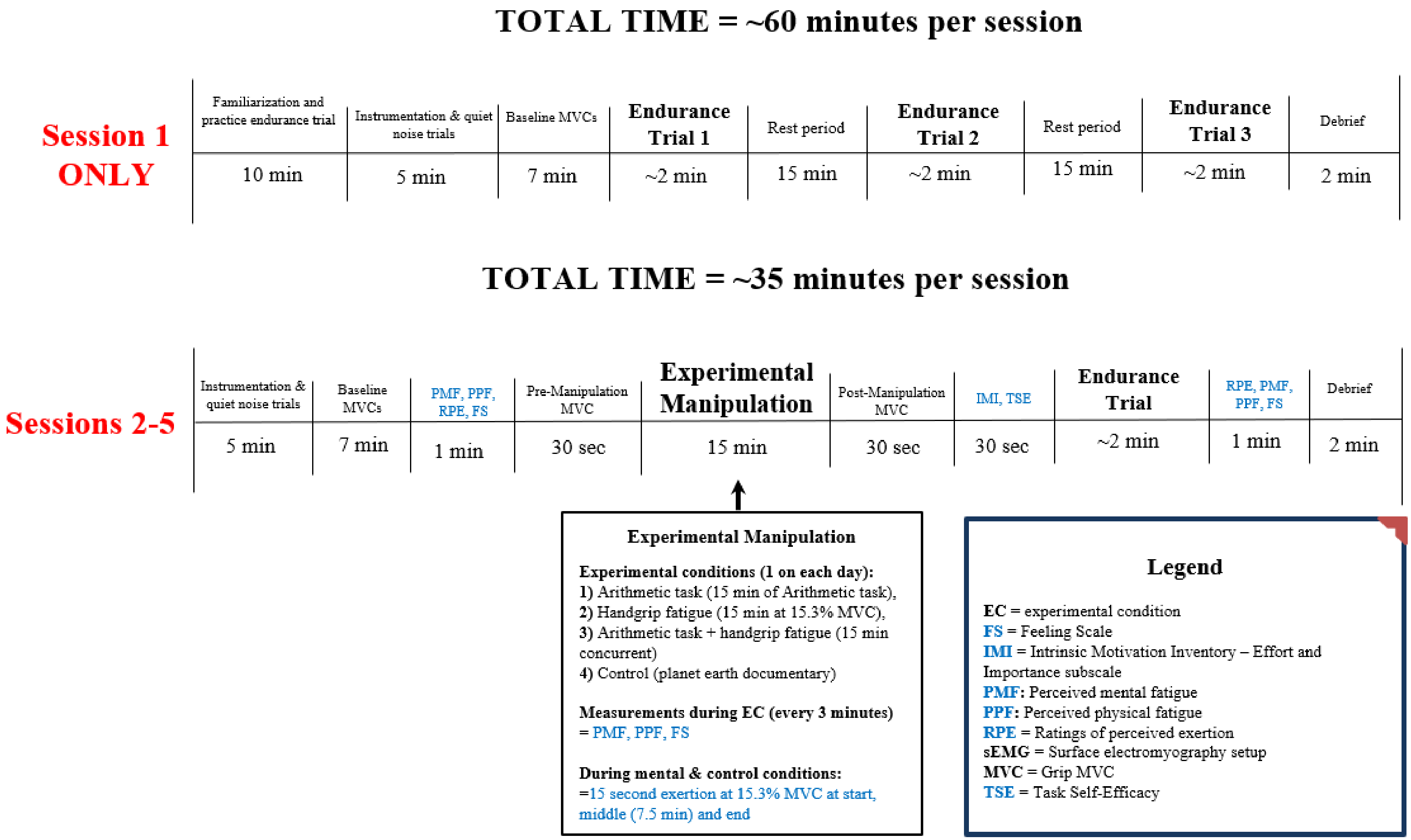

Figure 25: Overview of the modified experimental protocol

4.1.3.2 Matching of Target Force

In this pilot study, though the target for the endurance task was to match a 50% MVC line, we decided to provide a range with upper and lower bounds, to serve as a ‘target’ for participants (as in La Delfa et al., 2014). The upper and lower ranges were error bands that were set at 55% MVC and 45% MVC, respectively. However, with this method, we found that participants often aimed for the lower range (45% MVC) rather than adhering to the target 50% MVC line during the endurance trials. This is evident when looking at the mean participant force in the endurance trials which was 47.9%. This is not ideal as some participants may not be working at the same contraction. To mitigate this issue, upper and lower ranges will not be used in the endurance trials and only the 50% MVC line will be used to guide participants. Keeping the dotted 50% MVC line will make measurements more accurate during the endurance trials as participants will only have the visual guide for the 50% MVC. The study by Graham and colleagues (2014) also utilized a real-time graphed line that showed participants visually how much force they were generating with a target static line at 50% MVC. The results from this pilot study can give direction that using a static line with upper and lower ranges can give room for more error in a study’s data when compared to a protocol that uses only a static line for participants to trace (Graham et al., 2014). By removing the upper and lower limits on the endurance trial and only keeping the 50% MVC line, we anticipate participants will exert closer to their true MVC level.

4.1.3.3 Selection of Different Forearm Muscles for EMG

In this pilot study, we recorded from the ECR and FCR muscles to track forearm muscle activity during the grip task. These muscles were selected to mimic prior similar research by (Mehta &

Parasuraman, 2014; Shortz and Mehta, 2017) The ECR often displayed substantial levels of activation during the handgrip tasks, however FCR had notable lower activation for all participants in all conditions, indicating relatively minimal involvement in this particular posture and grip task. As such, another modification in the future study would be including flexor carpi ulnaris (FCU). Other studies have used the FCU in hand gripping tasks and our own examinations in lab have noticed notable muscle activation of the FCU during our gripping task (Mehta and Agnew, 2011; Graham et al., 2014; Potvin et al., 2004). The study by Mehta and Agnew (2011) used the FCU in addition to the ECU, FCR and ECR and reported in their rationale that these muscles are active in gripping and arm support. The study by Graham and colleagues (2014) used the FCU with the same exertion level and gripping task as our endurance trials which provides further evidence to incorporate the FCU into the full-scale study. In addition to the FCU, the flexor digitorum superficialis, extensor digitorum communis and extensor carpi ulnaris are used in gripping tasks and may give more reliable EMG and force variability data if included in the full-scale study (Keir and Mogk, 2007).

4.1.3.4 Implementation of Arousal Scale

In this pilot study, participants completed an arithmetic task in the mental fatigue condition. Although our mental fatigue condition did induce mental fatigue in participants, it is possible that the arithmetic task was stressful for participants as they had to verbally count out loud while doing the task and they may have a fear of incorrectly completing the task in front of the researchers. When participants are stressed, they may release adrenaline which can boost physical performance (Larsson et al., 1995). Thus, if the arithmetic task was stressing participants and inducing adrenaline release, this may explain the conflicting data seen in the force fluctuations and performance error results. Another possible alteration to the study could be to include a scale to measure arousal such as the Activation-Deactivation Adjective Check List that assesses energy, tiredness, tension, and calmness (Graham and Bray, 2015; Thayer, 1986). This scale could be used in conjunction with the PMF, PPF, RPE and FS scales used in the study protocol in order to assess stress (tension).

4.1.4 Research Relevance

This research is not only useful to the working population, as discussed before, but it is also applicable to the general public as muscle fatigue and mental fatigue are applicable to everyone and apply to day-to-day activities. For example, in Canada many individuals drive to work or on road trips when on vacation. Driving for long periods of time may induce mental fatigue and with long hours of gripping the steering wheel this may induce neuromuscular fatigue. When coupled with Canadian weather such as when driving on snowy and icy roads, driving when fatigued may be hazardous and increase the risk of preventable accidents on the road. In the workplace, impairment in motor function due to fatigue can affect an individual’s ability to do their jobs safely and effectively. Mental and forearm muscle fatigue can also lead to musculoskeletal disorders. In working conditions, such as the conditions in the medical field, often times there is not intense muscle use, and signals of fatigue may go unnoticed (Lundberg et al., 2002). However, even if muscle fatigue is minimal, motor units are still being used and continuous low-level fatigue can still cause the motor units to become overloaded over time.

Mental fatigue is very common in the medical field and since mental fatigue also activates motor neurons, it will not allow muscles to fully be at rest, even when healthcare professionals are on their break or have gone home. This lack of muscle rest is a risk factor for developing muscle pain and musculoskeletal disorders. In the modern work environment, there is a massive weight on efficiency, high work pace, and competitiveness. This heavily contributes to mental stress on workers and in turn, makes them work harder at their own detriment (Lundberg et al., 2002). Fatigue can reduce a medical professional's work ability and increase the risk of medical errors which in turn can compromise the safety and wellbeing of both patients and medical professionals (Da Silva et al., 2016; Cai et al., 2018). Among female medical personnel in 54 Chinese hospitals, there was a high prevalence of fatigue with 83.88% of physicians, 84.96% of nurses, 82.29% of medical technicians and 68.46% of administrators experiencing fatigue (Cai et al., 2018). Now more than ever, the COVID-19 pandemic has likely created elevated levels of both mental and neuromuscular fatigue with medical professionals working long hours and under various stressors. Nurses have been working long hours and experience continuous negative psychological problems such as symptoms of stress, anxiety, and depression (Zhan et al., 2020). Mental fatigue is also caused by long hours of stress which can decrease concentration, motivation and alertness (Zhan et al., 2020). Due to the pandemic nurses must use various personal protective equipment (PPE) such as gowns, goggles, face shields, and N95 masks for extended periods of time which is physically uncomfortable over long periods of time (Zhan et al., 2020). This additional equipment and continuous efforts on the front line likely contribute to neuromuscular fatigue and when coupled with mental fatigue, can increase the risk of medical errors and ability to work (Zhan et al., 2020; Cai et al., 2018).

This research will also help shed light on how mental and muscle fatigue can collectively be harmful to upper limb strength and accuracy which can lower quality of care from health care professionals and the increased risk of pain and musculoskeletal disorders will cause an increase in days away from work (Mehta & Agnew, 2011). Many industries require workers to perform repetitive tasks such as computer-based work, assembly jobs, and other labor jobs (Mehta & Agnew, 2013). Many of these jobs have low levels of static work which also gradually overload motor neurons which is a risk factor for musculoskeletal disorders (Mehta & Agnew, 2013). When mental fatigue is added to this, it can influence motor recruitment efficiency which increases the risk of workplace injuries (Mehta & Agnew, 2012). Lost time claims of the upper limbs account for 14.8% of all workplace injuries in Canada in 2020 which indicates that there is a significant need to research fatigue in the upper limbs (WSIB, 2021). The findings from this study will demonstrate the importance of managing muscle and mental fatigue in the workplace and in recreational activities. In the workplace, load should be suited to the strength of the worker to minimize muscle fatigue and frequent breaks along with destressing protocols should be implemented to reduce mental fatigue and ensure muscles are able to recover during and after work.

To summarize, muscle and mental fatigue can cause impairment in motor function, which can risk the ability of workers to complete their jobs safely, cause continuous low-level fatigue (causing lack of muscle rest) and can cause long-term pain or musculoskeletal disorders. This research will help explore how mental and muscle fatigue can collectively and independently be harmful to upper limb strength, endurance, and accuracy. There has been no literature that has investigated the independent the effects of mental or neuromuscular fatigue on subsequent physical performance when compared to the combined effects of both mental and neuromuscular fatigue on subsequent physical performance within a single study.

4.1.5 Key Findings

The concurrent condition and physical condition showed the greatest decreases in endurance time when compared to the mental fatigue and control conditions. MVCs decreased in the physical condition and decreased further in the concurrent condition; however, MVCs increased for the control and mental condition. Interestingly, force variability decreased in the concurrent condition, when compared to the mental and physical conditions that increased in force variability. Additionally, performance error decreased in the physical and concurrent conditions while performance error increased in the mental and control conditions.

EMG amplitude, when comparing the second endurance trial to the first endurance trial increased the most in the physical condition and increased slightly in the concurrent condition but decreased in the control and mental conditions. During the experimental manipulation, EMG amplitude increased in all experimental conditions for the ECR when compared to the control condition. However, for the FCR EMG amplitude decreased in all experimental conditions when compared to the control condition. Furthermore, MnPF decreased in all conditions between endurance trials, but interestingly the control condition had the greatest decrease in MnPF when compared to the experimental conditions. MnPF during the experimental manipulation for the ECR decreased in all experimental conditions when compared to the control condition and MnPF decreased for the mental and concurrent fatigue condition for the FCR when compared to the control however, the physical condition increased in MnPF.

The goal of this pilot study was to compare the independent effects of physical and mental fatigue and a control (no fatigue) condition against the effects of concurrent physical and mental fatigue on subsequent physical performance (see section 2.5.1). Considering the findings from the present study, the results suggest that when mental and physical fatigue are combined, they exhibit negative carryover effects on endurance time and upper limb strength but positively affect force fluctuations and performance error. However, results on aEMG and MnPF are still inconclusive and when considering the limitations of this study, require further research.

4.1.6 Limitations and Future Directions

The current pilot study provides a comprehensive insight on how mental fatigue and neuromuscular fatigue affect subsequent physical performance both independently and concurrently. However, there are limitations in this pilot study that must be addressed. First, the study had a small sample size (n=4), which limits the findings of this study to be interpreted as trends and directions for the future large-scale study. Furthermore, this study did not have an adjustable chair or desk. Participants sat on a fixed chair and the handgrip transducer was on a fixed desk which may have caused participants to have slightly different arm positions compared to other participants. The arms also were not isolated which may allow participants to unintentionally use other muscle groups to aid their endurance or strength values. The fatiguing protocol may not have sufficiently induced enough physical fatigue in participants as participants exerted intermittently at 15.3% MVC during the EM. The mental arithmetic test may not have induced substantial mental fatigue when compared to previous studies that utilized the Stroop task. The arithmetic test was chosen for this study to allow participants to concurrently perform a mentally fatiguing task alongside a physically fatiguing task without diverting attention away from the force matching task on the screen. Future research should try to incorporate a Stroop task in the concurrent fatiguing task in addition to the handgrip fatiguing task. Finally, the population also mainly consisted of a younger demographic and there can be age-related differences between adults, older adults, or children.

Future studies can explore how well a handgrip fatiguing task is able to induce central fatigue vs peripheral fatigue through the use of instrumentation such as EEG, TMS or muscle stimulations.

4.2 - Conclusion

This pilot study has explored how both mental fatigue and neuromuscular fatigue affect physical performance both independently and concurrently. Though these results can only be viewed as initial trends because of a small sample size, there is initial support for concurrent mental and physical fatigue leading to a more substantial detrimental effect to handgrip endurance and strength. However, some of our other measurements (i.e., force fluctuations, performance error) produced inconsistent findings, but these were likely attributable to the larger intra- and inter-participant variability typically associated with these measures. EMG amplitude and MnPF results were also inconclusive, at this point, when comparing between endurance trials and across experimental conditions. When looking at ECR and FCR together, aEMG increased for the physical and concurrent condition but decreased for the mental and control conditions while MnPF was observed to have an increase in all conditions. While our current findings for aEMG and MnPF are incomplete and contradictory to previous research, our findings for endurance time and grip strength are consistent with our hypotheses on foundational previous research. This pilot study also identified several areas for experimental refinement in the large-scale study, including implementing a familiarization session, only using a post-measurement endurance trial, removing upper and lower ranges during endurance trials, and measuring the FCU muscle in addition to the ECR and FCR. Although no strong conclusions can be drawn from the current results, they can be used to observe trends to refine these suggestions for the future larger-scale study.

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Appendices

Appendix A – Consent Form

<u>Consent Form to Participate in a Research Study</u>

COVID-19 UPDATED VERSION

All aspects of this study have been revised to include all possible risk mitigation strategies against COVID-19. Please see appended document at the end of this consent form for specific procedures and protocols regarding COVID-19

Title of Research Study: The effect of cognitive and physical muscle fatigue on upper extremity neuromechanics

Name of Principal Investigator (PI): Dr. Nicholas La Delfa

PI's contact number(s)/email(s): 905-721-8668 ext 2139 / nicholas.ladelfa@ontariotechu.ca

Names(s) of Co-Investigator(s), Faculty Supervisor, Student Lead(s), etc., and contact number(s)/email(s):

1. Rahul Pabla, MHSc Student (rahul.pabla@ontariotechu.ca);

2. Jeffery Graham, Postdoctoral Fellow (jeffrey.graham@ontariotechu.ca)

Departmental and institutional affiliation(s): Faculty of Health Sciences, Ontario Tech University

External Funder/Sponsor: none

<u>Introduction</u>

You are invited to participate in a research study entitled "*The effect of cognitive and physical muscle fatigue on upper extremity neuromechanics".* You are being asked to take part in a research study. Please read the information about the study presented in this form. The form includes details on the study's procedures, risks and benefits that you should know before you decide if you would like to take part. You should take as much time as you need to make your decision. You should ask the Principal Investigator (PI) or study team to explain anything that you do not understand and make sure that all of your questions have been answered before signing this consent form. Before you make your decision, feel free to talk about this study with anyone you wish including your friends and family. Participation in this study is voluntary.

This study has been approved by the Ontario Tech University Research Ethics Board REB [16103] on [2020/12/10].

Purpose and Procedure:

Please note, if you feel that you are in a vulnerable group with respect to COVID-19 effects (e.g. senior, immunocompromised, living with individuals that may be susceptible to COVID-19), we recommend that you choose not to participate in the study.

Purpose:

Previous research (Kennedy at al, 2013) found that performing an endurance handgrip task can cause central fatigue (fatigue in your central nervous system) alongside peripheral fatigue (fatigue in the muscles), and both types of fatigue can lead to decreases in handgrip strength. Many studies have found links between mental fatigue and impaired muscular performance. A study that looked at mental fatigue and grip force on shoulder strength found decreases in shoulder force between MVCs when paired with a demanding cognitive test (i.e., the Stroop test) to induced mental fatigue (Mehta & Agnew, 2011). This indicates that a mental task such as the Stroop test may interfere with physical muscle exertions in the same way that additional physical tasks interfere with MVCs. This suggests that the cognitive load that is stimulated by the Stroop test may affect the central nervous system (CNS) (Macdonell, 2005).

Though studies have found that mental fatigue and muscle fatigue exposure can affect physical performance independently, no study has compared physical vs. mental fatigue effects on upcoming tasks and in addition to this, no study has compared if a combination of physical and mental fatigue has an even worse negative effect on upcoming tasks. For example, is a similar fatigue and recovery response observed when participants conduct a fatiguing protocol with mental and physical fatigue combined vs. mental and physical fatigue independently? Both exposures will eventually lead to significant muscle fatigue, but will a combination of the two result in a more greater deteriorating effect? As such, the purpose of this study is to: 1) evaluate interactions between mental fatigue and physical fatigue and 2) evaluate if differences in task-related outcome variables such as hand grip strength and endurance are affected by the different fatigue exposures

We **hypothesize** that: 1) muscle fatigue and mental fatigue protocols will result in muscle fatigue and negatively affect hand grip performance directly following the protocol (i.e. post vs. pre); and 2) the combined muscle and mental fatigue protocol will lead to reduced handgrip endurance and grip strength as well as greater alterations in muscle activity and force fluctuation.

We are seeking healthy participants between 18 and 35 years of age. We are looking for participants who do not have a history of hand or forearm pain severe enough to have sought medical intervention or taken more than 3 days off work in the past 12 months. Participants who are colourblind or use an implanted electronic device are not eligible to participate in this study. You have been invited to participate in this study because you are free from recurrent hand and forearm pain or disorders, and therefore meet the required criteria for participation.

Procedures:

Please refer to the Appendix at the end of this consent form for additional information on COVID-19 risk mitigation pertaining to this study. Specific protocols exist for entering and exiting the building, maintaining physical distancing, wearing non-medical face masks at all times and pre-screening for COVID-19 symptoms. Please review this document (Appendix A) carefully before also considering the following procedures that are specific to this experimental study.

Upon arriving to the laboratory (UAB 356), you will be asked to review the consent form and provide written and oral consent once you are fully satisfied with what this study involves. You will then be asked to complete the Edinburgh Handedness Inventory (EHI) questionnaire and the Participant demographic and eligibility form. Once deemed to be eligible to participate, you will be asked to change into a tee-shirt or other type of shirt that leaves your dominant forearm and hand exposed. You will then be instrumented with some non-invasive surface electromyography (sEMG) sensors that will be placed over your forearm muscle so that we can track the muscle activity of your forearm throughout the experimental session. These sensors passively record your muscle activation, like a microphone picking up the electrical signal produced by your forearm muscles. This setup will take approximately 15 minutes.

Next, we will be conducting baseline measurements which involves determining your forearm strength. You will be asked to squeeze a handgrip dynamometer as hard as you can for about 5 seconds, three separate times each. The handgrip dynamometer is a device that measures the force produced by your grip. You will then be asked to perform and handgrip endurance trial and squeeze the handgrip at 50% of your maximum squeeze for as long as you can. Upon completing the handgrip endurance trial, we will then ask you to complete one of four experimental manipulations for 15 minutes which include: 1) a control condition (watching a documentary), 2) a handgrip fatigue protocol, 3) a mental fatigue protocol (i.e., Stroop test), or 4) performing the handgrip fatigue and mental fatigue protocols at the same time; the order of which will be randomized for every participant. You will perform one of the four conditions in the first session. This means we will ask you to visit the lab on **four separate days**, separated by at least 3 days to allow for adequate recovery.

Visit	**Study procedure/tests/interventions**	**Duration of visit**
Visit 1	Control condition	1-1.5 hours
Visit 2	Mental fatigue condition	1-1.5 hours
Visit 3	Handgrip fatigue condition	1-1.5 hours
Visit 4	Mental and handgrip fatigue condition	1-1.5 hours

*Please note, the particular order of conditions will be randomized. Therefore, on your Visit #1, you may actually perform the 'mental and handgrip fatigue condition'. All 4 conditions will be completed by the end of the study.

The **handgrip fatigue condition** will require you to alternate squeezing the handgrip at 30% of your maximum for 15 seconds followed by 15 seconds of rest for 15 minutes. The **mental fatigue condition** will require you to say aloud different coloured words whereby the printed text (e.g., read "red") is mismatched with the ink colour of the text (e.g., say "yellow") for 15 minutes – there is no physical fatigue exertion on this day. The **control condition** involves simply watching a documentary (Planet Earth) for 15 minutes while seated at a table - there is no physical fatigue exertion on this day. The **combined condition (handgrip and mental fatigue)** will require you to perform the tasks in the handgrip fatigue condition and the mental fatigue condition at the same time for 15 minutes.

After completing either one of the three fatiguing protocols, or the control condition, depending on the above-mentioned randomized order, you will then be asked to perform both the a maximum handgrip squeeze and then another handgrip endurance trial at 50% of your maximum squeeze for as long as you can. In order to continue to track the changes in strength and muscle activation during the time in which muscles are recovering after the second endurance trial, we will continue to obtain the grip strength MVC values during the recovery period at 5 minutes, 10 minutes, and also at 15 minutes after the fatiguing protocol is completed. You will be seated during this time. Once all recovery measurements have been made, we will then assist you in removing the sEMG sensors and the study will be concluded for that day.

Potential Benefits:

You will not *directly* benefit from participating in this study. However, by participating, you will be contributing to our scientific knowledge on how muscle fatigue and mental fatigue affect performance of the upper limb, which can have important implications in the workplace for professions such as dentistry, surgery or office work. If you are a kinesiology student, you will get to learn more about the research process that occurs which is fundamental to the University.

Potential Risk or Discomforts:

A vital component of this study is to measure your handgrip endurance and induce forearm muscle fatigue, which commonly results in a 'burning' sensation as lactic acid builds in the muscles. For instance, this is the same sensation you may feel when working out at a gym or carrying a heavy box for an extended period of time. As soon as this discomfort becomes intolerable, notify the investigators immediately. However, this burning sensation will be alleviated in a relatively short period of time after exposure to the handgrip endurance task or the handgrip muscle fatigue protocol. Additionally, due to the handgrip endurance and fatigue protocol specifically, delayed onset muscle soreness (DOMS) is likely in the forearm muscles in a period 24-48 hours following the study. This is a transient, normal response, similar to what you may experience after resistance training at the gym. Remember that you can withdraw from the study at any time, for any reason, without penalty. Your safety is the number one priority and you should not feel obligated to continue if you are in severe discomfort. However, you may experience mild discomfort with this task and will be asked to report your comfort levels periodically.

Secondly, the surface EMG markers pose a very low risk of skin irritation from the alcohol swab, razor, light abrasion, electrode gel or tape. These complications are not serious and they should subside within a few days. Participants will have access to soap and water to cleanse the affected area if this occurs. However, if these irritations persist, we recommend that the participant goes directly to the campus health clinic for medical advice and then contact the researchers to report the adverse event. If the campus health clinic is closed or if there is a medical emergency, participants can go to Lakeridge Health located at 136 Hospital Court Oshawa, ON.

Use and Storage of Data:

All collected data will be initially stored on a password protected computer in the Occupational Neuromechanics & Ergonomics (ONE) Laboratory (UAB 355), then moved to an encrypted and password protected hard drive, which will be stored in a locked filing cabinet in the ONE lab (UAB 355). All data will also be backed up on an encrypted and password protected Google Drive administered by Ontario Tech University and approved by our Research Ethics Board (REB). All digital experimental data will be identified with a randomly assigned participant code.

All raw data from EMG and scales will be kept indefinitely. All participant consent forms, questionnaires and any other potential identifying information (e.g. sex, age and anthropometric data) will be locked in a separate location; a locked filing cabinet in Dr. La Delfa's secure office. All consent forms, questionnaires and identifying information will be retained for a period of 2 years before being destroyed. However, once all identifying information is destroyed after 2 years, we will have no way of linking your data with you. Please note that if your data is considered for use in a secondary analysis, we will seek appropriate REB approval before undertaking this analysis. Additionally, we will ask for your pre-consent to use these data in a potentially secondary analysis, in case this analysis occurs after the period of 5 years and we lose to ability to identify your data.

All information collected during this study, including your demographic and anthropometric data, will be kept confidential and will not be shared with anyone outside the study unless required by law. You will not be named in any reports, publications, or presentations that may come from this study.

Confidentiality:

Your privacy shall be respected. No information about your identity will be shared or published without your permission, unless required by law. Confidentiality will be provided to the fullest extent possible by law, professional practice, and ethical codes of conduct.

This research study includes the collection of demographic data which will be aggregated (not individually presented) in an effort to protect your anonymity. Despite best efforts it is possible that your identity can be determined even when data is aggregated. However, we will minimize potential of this occurrence by refraining from presenting any individual data points (for example in a scatter plot where any identifying information is presented on one axis). In practice, we typically only present mean and standard deviation data, which will make it impossible to identify any individual participant in our research.

Voluntary Participation:

Your participation in this study is voluntary and you may partake in only those aspects of the study in which you feel comfortable. You may also decide not to be in this study, or to be in the study now, and then change your mind later. You may leave the study at any time without affecting your academic standing, and/or research credit. You will be given information that is relevant to your decision to continue or withdraw from participation. Such information will need to be subsequently provided.

Right to Withdraw:

Your participation in this study is voluntary and you are free to decline without providing a reason. Throughout the research process, you are free to withdraw from participation at any time without repercussion. If you withdraw from the research project at any time, any data or human biological materials that you have contributed will be removed from the study.

Conflict of Interest:

Researchers have an interest in completing this study. Their interests should not influence your decision to participate in this study.

Compensation, Reimbursement, Incentives:

As compensation for your time spent participating in this study, you have the right to select one (1) of two (2) potential offers. You may select either:

1. a 50$ gift card of your choice
2. Extra course credit added to the Kinesiology course of your choosing (must be from the list of pre-confirmed course options, which we will provide). Participants are eligible up to a maximum of 2% of the total course grade.

Your participation in this study will not have any direct expense associated to you.

Debriefing and Dissemination of Results:

The data for this research may be submitted to scientific conferences and peer-reviewed journals for publication. Any published data will be free of any potentially identifying information. If you wish to receive an aggregate of the research findings, please check the box at the bottom of this form and provide an email address to receive the results.

Participant Rights and Concerns:

Please read this consent form carefully and feel free to ask the researcher any questions that you might have about the study. Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Research Ethics Office – researchethics@uoit.ca or 905.721.8668 x. 3693.

If you have any questions concerning the research study or experience any discomfort related to the study, please contact Rahul Pabla at rahul.pabla@ontariotechu.net or Dr. Nicholas La Delfa at nicholas.ladelfa@uoit.ca. By signing this form you do not give up any of your legal rights against the investigators, sponsor or involved institutions for compensation, nor does this form relieve the investigators, sponsor or involved institutions of their legal and professional responsibilities.

Consent to Participate:

1. I have read the consent form and understand the study being described;
2. I have had an opportunity to ask questions and those questions have been answered. I am free to ask questions about the study in the future;
3. I freely consent to participate in the research study, understanding that I may discontinue participation at any time without penalty. A copy of this consent form has been made available to me.
4. There may be additional risks to participating in this research during the COVID-19 pandemic that are currently unforeseen and, therefore, not listed in this consent form.
5. If you should develop any symptoms of COVID-19 after completion of this study or during the study, please contact the researchers: Nicholas.ladelfa@ontariotechu.ca, Jeffrey.Graham@ontariotechu.ca or rahul.pabla@ontariotechu.net at your earliest convenience.

____

Print Study Participant's Name Signature Date

My signature means that I have explained the study to the participant named above. I have answered all questions.

____

Print Name of Person Obtaining Signature Date

Secondary Use of Research for Future Research Purposes

1. I understand the possible need for secondary research uses of my research data for future research use and provide consent for the use of my data to be used in future studies.
2. The research team has informed me that a separate REB application will be submitted for the secondary use of data for any future research purposes.

Participant must initial ________ Yes ________No

Follow-up Summary

☐ Yes, I would like to receive a summary of the study's results. Please send them to this email address ____.

☐ No, I do not want to receive a summary of the study's results.

Appendix A – COVID 19 Procedures in addition to protocols documented in Consent Form

COVID-19 Related Information

Please find information below regarding the risk mitigation strategies we will be employing in order to minimize the risk of COVID-19 exposure during this research study.

Active Screening

This is conducted online before you attend each experimental session. The questions are based on Ontario Ministry of Health Guidelines.

To complete online screening please visit the university's pre-screening tool at:
https://ssbp.mycampus.ca/apex/r/banner/covid19-prescreen168/login

Please note that if you answer **yes** to any of the questions in the online Covid screening survey, you will be advised to:

- not come to campus in person for at least 14 days
- get tested for COVID-19;
- complete the Ontario Government's self-assessment; and
- contact an appropriate authority such as your family physician, local medical officer of health or Telehealth Ontario.
- Please note: If you have screened positive, is not equivalent to a confirmed diagnosis of COVID-19, but we need to screen for your safety and that of others.

Passive Screening

There will be signage at points of entry to the university and the laboratory, reminding you of possible COVID-19 symptoms, should you have developed any since completing the online survey.

Coming to Campus

Access to campus is currently limited. As such, a member of the research team will request permission from Ontario Tech University for you to come to campus. You may be required to check in with security prior to visiting the laboratory. We will confirm procedural details prior to your visits.

Because you are coming on campus, the following safety protocols must be followed

- ✓ Screening
- ✓ Use of non-medical masks or face covering while participating in the research study
- ✓ Follow instructions provided to you with respect to arriving at the study location, including entry points, designated waiting areas and washrooms, timing of arrival
- ✓ Hand washing
- ✓ Precautions taking public transit or travelling to the research site
- ✓ Physical distance (maintaining 2-meter distance from others)
- ✓ Personal Protective Equipment (PPE) provided to participants by research team

- Please note, all researchers will wear a mask and face shield at all times. You will be asked to bring a mask or face covering from home, and will be asked to wear it while walking through any of the campus buildings. If you forget to bring a mask, one will be provided to you by the research team.

Laboratory Session: Entering and Exiting the Laboratory

- A member of the research team will escort you from the back entrance of the Science building to the laboratory.
- When you enter the lab, a team member will write down your cell phone on a sheet in the laboratory. We are required to do this, should there be an outbreak, for contact tracing purposes. This piece of paper will be kept locked in the lab and will be destroyed once the study is complete.
- Researchers will only conduct the study on one participant at a time. To reduce any possible contact with other participants, there will be time between study appointments. In addition to this, if a participant arrives early to their session, they will be instructed to adhere to distancing markers on the floor to ensure they stay at least 2 meters away from the lab door and potentially other participants.

Personal protective equipment and handwashing

Please note that you are required to wear a mask on campus, and sanitize your hands prior to entering the lab. All protocols within the lab relevant to social distancing, personal protective equipment, sanitizing, and contact tracing are being conducted in accord with provincial guidelines by the Ministry of Health. This includes maintaining 2 metres of social distancing when passing others in common spaces. There is signage on the UAB 356 lab door and inside the lab itself that will remind you to maintain social distancing, wash your hands frequently and to wear a mask at all times. In addition to this, there are distancing markers placed on the floor in the hallway outside of the lab that indicate where you can safely stand.

The following surfaces in the research area are routinely cleaned, and then disinfected with medical grade disinfectant effective against COVID-19.

- Chairs, tables and specialized research equipment
- Any exercise equipment
- All surfaces in laboratory rooms
- Computers, telephone and other devices in laboratory or common areas
- Entry, reception, waiting, washroom and transition areas such as hallways, doorways etc.
- Other high-touch surfaces such as light switches, doorknobs, toilets, taps, handrails, countertops, touch screens, mobile devices, phones, keyboards, clipboards, pens, etc.

Measurement sessions:

Please note, all researchers will wear a mask and face shield at all times. You will be asked to bring a mask or face covering from home, and will be asked to wear it during the measurement sessions. You will be required to wear a mask for the whole duration of each session you attend.

You will be required to sanitize your hands before entering the laboratory area where the data will be collected.

To maximize your safety, prior to data collection, a member of the research team will spray and wipe down all contact surfaces with a medical grade disinfectant effective against COVID 19.

Prior to exiting the laboratory, you will be asked to use the provided hand sanitizer once more.

Only 1 participant will be measured at a time with 2 researchers in the laboratory. Each laboratory has been approved to have a maximum of 4 people according to the laboratory size.

Additional Notes:

i. If you feel that you are in a vulnerable group with respect to COVID-19 effects (e.g. senior, immunocompromised, living with individuals that may be susceptible to COVID-19), it may be best that you do not participate in the study.

ii. We will be collecting personal contact information that we must retain in order to follow up with you and/or conduct contact tracing if you may have been exposed to COVID-19 in coming to the research site. As a result, we cannot guarantee privacy and confidentiality of your participation in the study. All personal contact information will be stored in a locked filing cabinet within the laboratory and will be destroyed 1 month following the last participant's data collection in this study

iii. We cannot guarantee anonymity, as the personal contact information does identify you as a participant.

iv. Contact information will be kept separate from data collection through the research study to allow for de-identification of the research data (If applicable, as detailed in the protocol).

v. During this time, the university may request information relating to all people entering and exiting our campus. As such please be advised that it may not be possible to keep your participation in a study confidential; however, no information about the data you share with us in the study will be shared outside of the research team

vi. You maintain your right to withdraw from the study, including research data (if applicable). If you do withdraw, we will continue to maintain your contact information and will only give it Durham Public Health and the University if required for contact tracing.

vii. There may be additional risks to participating in this research during the COVID-19 pandemic that are currently unforeseen and, therefore, not listed in this consent form.

viii. If you think you have COVID-19 symptoms or have been in close contact with someone who has it, use the Government of Ontario's COVID-19 self-assessment tool and follow the instructions it provides to seek further care. In addition, you must inform the Principal Investigator immediately for follow up.

Appendix B – Participant Inclusion and Exclusion:

Title: The effect of cognitive and physical muscle fatigue on upper extremity neuromechanics.

This study has been approved by the UOIT Research Ethics Board REB [#16103] on 2020/12/10. Please note the data collected on this form will be stored separately from your experimental data and locked in a secured filing cabinet.

If you would like a copy of this consent form for your records, please ask the investigators.

Received Copy: YES NO

Name: ____

Biological Sex (circle one): Male Female

Date of Birth: ______________________________ Current Age: __________

Email Address: ____

Have you experienced hand or forearm pain in the past 12 months?	YES	NO
Are you colour blind?	YES	NO
Have you sought medical intervention or treatment for hand or forearm pain in the past 12 months?	YES	NO
Would you like to be notified with the aggregate results of the study when they are released in summer of 2020 via email?	YES	NO
I hereby give consent for the information contained in this package to be used for the purposes of this study and in future research as long as there is no way that I can be identified.	YES	NO

Anthropometric Data to be collected by Experimenters:

Height (cm): ______ Mass (kg): ______

If you have any questions concerning the research study, please contact the researcher Rahul Pabla at rahul.pabla@ontariotechu.ca . Alternatively, you can contact the principal investigator Dr. Nicholas La Delfa at 905.721.8668 x2139 or nicholas.ladelfa@uoit.ca.

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Research Ethics Coordinator –researchethics@uoit.ca or 905.721.8668 x. 3693.

________________________________ ______________________________

Participant Signature Date

Appendix C – Participant Screening Questionnaire

PARTICIPANT INFORMATION

Name: ____

Date: ________________

Age: _____

SCREENING QUESTIONNAIRE	YES	NO
1. Have you had a hand or forearm injury and/or experienced any pain in your dominant hand or forearm in the last 12 months?		
2. Are you colorblind?		
3. Do you use an implanted electronic device such as a pacemaker?		
4. Do you know of <u>any other reason</u> why you should not do physical activity? If so, please note it down in the blank space below.		

Appendix D – COVID-19 Screening Questionnaire

COVID-19 Screening Questionnaire

Do you have any of the following new or worsening symptoms or signs? Symptoms should not be chronic or related to other known causes or conditions.

☐ Fever or chills

☐ Cough

☐ Difficulty breathing or shortness of breath

☐ Sore throat, trouble swallowing

☐ Runny nose/stuffy nose or nasal congestion

☐ Decrease or loss of smell or taste

☐ Nausea, vomiting, diarrhea, abdominal pain

Regarding the symptoms listed above

☐ None apply

☐ At least one applies

Have you travelled outside of Canada in the past 14 days?

☐ Yes

☐ No

Have you had close contact with a confirmed or probable case of COVID-19?

☐ Yes

☐ No

By submitting this form, I certify the claims made are true. I acknowledge that misrepresentation places others at risk.

Name: **Date**:

Appendix E – Feeling Scale

Feeling Scale

How are you feeling right now?

+5 Very good

+4

+3 Good

+2

+1 Fairly good

0 Neutral

-1 Fairly bad

-2

-3 Bad

-4

-5 Very bad

Appendix F – Intrinsic Motivation Inventory

For each of the following statements, please indicate how true it is for you, using the following scale:

1	2	3	4	5	6	7
Not at all true			**Somewhat true**			**Very true**

For the <u>endurance task</u> I'm about to do:

1. I am going to put a lot of effort into this task. ______
2. I am going to try very hard to do well at this task. ______
3. I am going to try very hard on this task. ______
4. It is important to me to do well at this task. ______
5. I am going to put a lot of energy into this task. ______

-- FOLD OVER ---

For each of the following statements, please indicate how true it is for you, using the following scale:

1	2	3	4	5	6	7
Not at all true			**Somewhat true**			**Very true**

For the <u>endurance task</u> I'm about to do:

1. I am going to put a lot of effort into this task. ______
2. I am going to try very hard to do well at this task. ______
3. I am going to try very hard on this task. ______
4. It is important to me to do well at this task. ______
5. I am going to put a lot of energy into this task. ______

Appendix G – Task Self Efficacy Scale

Task Self-Efficacy

Compared to last time, how confident are you in your ability to perform the endurance task?

"I am confident in my ability to last…"

Performance Rating	**Yes/No (Y or N)**	**Strength 0-10**
A. 25% as long		
B. 50% as long (half as good as last time)		
C. 75% as long		
D. 100% as long (the same as last time)		
E. 125% longer		
F. 150% longer		
G. 175% longer		
H. 200% longer (twice as good as last time)		

Appendix H – Rating of Fatigue Scale

Rating-of-Fatigue (ROF) Scale

Please rate your overall fatigue level

10 **Total Fatigue and Exhaustion – Nothing Left**

9

8

Very Fatigued

7

6

5 **Moderately Fatigued**

4

3

A Little Fatigued

2

1

0 **Not Fatigued at All**

Appendix I – Rating of Perceived Physical Exertion

Ratings of Perceived Physical Exertion

0	Nothing at all
0.3	
0.5	Extremely weak
1	Very weak
1.5	
2	Weak
2.5	
3	Moderate
4	
5	Strong
6	
7	Very Strong
8	
9	
10	Extremely Strong

Appendix J –Perceived Mental Fatigue and Perceived Physical Fatigue Scales

Baseline

Please mark (X) on the line the point that you feel represents your perception of your current state of **MENTAL FATIGUE**.

None at all 0 ____ 100 Maximal

Feeling Scale:
____

Please mark (X) on the line the point that you feel represents your perception of your current state of **PHYSICAL FATIGUE**.

None at all 0 ____ 100 Maximal

Pre-Experimental manipulation

Please mark (X) on the line the point that you feel represents your perception of your current state of **MENTAL FATIGUE**.

None at all 0 ____ 100 Maximal

Feeling Scale:
____

Please mark (X) on the line the point that you feel represents your perception of your current state of **PHYSICAL FATIGUE**.

None at all 0 ____ 100 Maximal

Experimental Manipulation

3 minutes

Please mark (X) on the line the point that you feel represents your perception of your current state of **<u>MENTAL</u> FATIGUE**.

Feeling

Scale:

____

None at all 0 ____ 100
Maximal

Please mark (X) on the line the point that you feel represents your perception of your current state of **<u>PHYSICAL</u> FATIGUE**.

None at all 0 ____ 100 Maximal

6 minutes

Please mark (X) on the line the point that you feel represents your perception of your current state of **<u>MENTAL</u> FATIGUE**.

Feeling

Scale:

____

None at all 0 ____ 100
Maximal

Please mark (X) on the line the point that you feel represents your perception of your current state of **<u>PHYSICAL</u> FATIGUE**.

None at all 0 ____ 100 Maximal

9 minutes

Please mark (X) on the line the point that you feel represents your perception of your current state of **<u>MENTAL</u> FATIGUE**.

Feeling

Scale:

____

None at all 0 ____ 100
Maximal

Please mark (X) on the line the point that you feel represents your perception of your current state of **PHYSICAL FATIGUE**.

None at all 0 ____ 100 Maximal

12 minutes

Please mark (X) on the line the point that you feel represents your perception of your current state of **MENTAL FATIGUE**.

None at all 0 ____ 100
Maximal

Feeling

Scale:

____

Please mark (X) on the line the point that you feel represents your perception of your current state of **PHYSICAL FATIGUE**.

None at all 0 ____ 100 Maximal

15 minutes

Please mark (X) on the line the point that you feel represents your perception of your current state of **MENTAL FATIGUE**.

None at all 0 ____ 100
Maximal

Feeling

Scale:

____

Please mark (X) on the line the point that you feel represents your perception of your current state of **PHYSICAL FATIGUE**.

None at all 0 ____ 100 Maximal

Post-Experimental manipulation

Please mark (X) on the line the point that you feel represents your perception of your current state of **MENTAL FATIGUE**.

Feeling

Scale:

____

None at all 0 ____ 100 Maximal

Please mark (X) on the line the point that you feel represents your perception of your current state of **PHYSICAL FATIGUE**.

None at all 0 ____ 100 Maximal