Exploring the Effects of Mental Fatigue on Perceptual Motor Task Performance and Kinematics

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

Mentally demanding tasks that require performance accuracy are common in several occupations. However, little is known about how mental fatigue can impact accuracy performance. Therefore, the purpose of this thesis was to examine the impacts of mental fatigue on performance accuracy and arm kinematics during dart throwing. Dart throw accuracy and kinematic performance were observed as two groups of participants performed two sets of dart throws, one group undergoing a mentally demanding task and one as a control. No significant changes in accuracy performance or kinematic variables were associated with mental fatigue apart from a significant decrease in shoulder angle of elevation at the end of dart throwing motions. However, notable variability was observed among all outcome measures, likely due to the complex unconstrained nature of this task. Further constraining this task may allow for further study of this phenomenon.

Keywords: Mental Fatigue; Ego Depletion; Accuracy; Kinematics; Dart Throwing

AUTHOR'S DECLARATION

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SARAH A. FITZGERALD

STATEMENT OF CONTRIBUTIONS

The works described in Chapter 3 were performed at Ontario Tech University within a laboratory operated by **Dr. Nick Wattie**. The collection of data presented in Chapter 3 was conducted with the help of **Matthew McCue.** Statistical analysis and statistical interpretation was conducted under the supervision of, and with feedback from **Dr. Jeffrey Graham.** Study design was conducted with input from **Dr. Nicholas La Delfa, Dr. Nick Wattie, Matthew McCue and Dr. Jeffrey Graham**. **Dr. Nicholas La Delfa** and **Dr. Jeffrey Graham** provided minor editorial suggestions to the contents of this thesis. However, all written content presented in this thesis is the work of my own.

I hereby certify that no part of this thesis has been published or submitted for publication. I have used standard referencing practices to acknowledge ideas, research techniques, or other materials that belong to others.

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 3

LIST OF FIGURES

CHAPTER 2

CHAPTER 3

Figure 3.27: Mean pre-intervention control group resultant errors in mm plotted against pre-intervention throw time in seconds.………………………...………………………………………………………… 69

CHAPTER 4

LIST OF ABBREVIATIONS AND SYMBOLS

cm	centimetres
mm	millimetres
m	metres
ISB	International Society of Biomechanics
CoM	centre of mass
Hz	hertz
NASA-TLX	NASA – task load index
IMI	intrinsic motivation inventory
TSES	task self efficacy scale
BTSCS	brief version of the trait self control scale
°	degrees
Deg	degrees
Deg/Sec	degrees per seconds
IMUs	inertial measurement units

Chapter 1. Thesis Introduction

Fatigue is known to have a notable impact on neuromuscular function and biomechanical performance. However, while an abundance of quality research has been conducted to examine the influence of neuromuscular fatigue on biomechanical performance, the impact of mental fatigue is not as well understood. In fact, a meta-analysis examining connections between mental fatigue and physical performance found only 73 articles pertaining to this matter (Brown et al., 2020). Recent literature has indicated that some common negative consequences that muscle fatigue can pose on physical performance might also appear in the presence of mental fatigue (Azevedo et al., 2016; Brown et al., 2020; Cutsem et al., 2017; Giboin & Wolff, 2019; Graham et al., 2014a, 2018; Graham & Bray, 2015; S. M. Marcora et al., 2009; Pageaux & Lepers, 2018; Smith et al., 2015). Considering this, a broader understanding of the impacts of this phenomenon is becoming increasingly vital for ergonomists and biomechanists to provide a safer environment for their clientele.

To better understand mental fatigue, it is first important to understand and identify the ways in which fatigue is defined within the literature. Fatigue has been defined within clinical literature as the depletion of energy stores resulting in tiredness, brain fog, or muscular weakness (Ishii et al., 2014). Within the field of kinesiology, fatigue is often defined using two broad categories, neuromuscular fatigue and mental fatigue. Neuromuscular fatigue refers to any physical exercise induced reduction in force or power (Bigland-Ritchie & Woods, 1984). This is a form of fatigue that originates from overloaded use of the peripheral neuromuscular system and can impact function in both the central and peripheral neuromuscular systems. Alternatively, mental fatigue is commonly defined as a psychobiological state caused by prolonged periods of cognitive exertion and a lack of motivation to fulfill cognitive demands (Boksem & Tops, 2008).

A greater understanding of the impacts that mental fatigue can have on physical performance is particularly important in the planning of safe workplace tasks. Workplaces often require employees to perform occupational tasks that involve some level of mental and/or cognitive work resulting in the accumulation of mental fatigue throughout the work day. There is a potential that this increase in mental fatigue might lead to reduced productivity and increased risk of injury, thus the biomechanical impacts of work-task based mental fatigue is becoming relevant within workplace health and safety conversations (Mehta & Agnew, 2012). As neuromuscular fatigue is an important consideration for the safety of employees within the workplace, the current lack of consideration for the impact that mental fatigue can have on function and performance is problematic.

One important factor to consider while examining neuromuscular and mental fatigue are the distinct physiological outcomes which result from each of these forms of fatigue. As previously mentioned, neuromuscular fatigue commonly impacts the function of the central and peripheral neuromuscular systems resulting in acute muscular weakness and decreased physical energy. Interestingly, the physiological outcomes of mental fatigue are more complex, with research indicating that mental fatigue can impact neuromuscular function along with mental and cognitive function. Research examining the impacts of mental fatigue on physiological function first provided evidence that mental fatigue reduces performance in cognitive based tasks (Baumeister, 1998; Baumeister, 2007; Baumeister et al., 2016). However, more recent literature has presented evidence that mental fatigue can also have a negative impact on movement biomechanics. It has been suggested that when participants enter a state of mental fatigue induced by the performance of cognitively demanding tasks, subsequent physical task performance (e.g. endurance, fine motor, and resistance exercise) are negatively impacted (Brown et al., 2020). Some limited evidence has also demonstrated a potential negative impact on perceptual motor task performance associated with mental fatigue (McEwan et al., 2013). However, this physiological consequence of mental fatigue has not been consistently demonstrated within the literature (Brown et al., 2020; Giboin & Wolff, 2019). As such, much remains unknown about the impacts that mental fatigue can have on tasks that require movement accuracy, such as perceptual motor tasks.

Understanding the impacts that mental fatigue can have on perceptual motor tasks is particularly vital as perceptual motor tasks are common for many individuals. Perceptual motor accuracy is required for the performance of many routine skills such as typing, handwriting, and walking upstairs or around obstacles. As previously mentioned, some recent literature has provided evidence that mental fatigue can negatively impact these tasks. One example of such research is a study in which participants threw a series of darts before and after mental fatigue was experimentally induced. In this study, the researchers observed a mean accuracy decrease among participants who were mentally fatigued when compared to control participants (McEwan et al., 2013). Yet, other studies have shown no significant impacts of mental fatigue alone on accuracy-based task performance. For instance, one study observed a significant decrease in performance accuracy associated with mental fatigue in combination with induced anxiety (Englert & Bertrams, 2012). In another study, which examined the influence of mental fatigue on changes in participants' ability to respond accurately to cues for action or inaction, no direct impact of mental fatigue on accuracy performance was observed (Head et al., 2017).

Some research has examined the underlying physiological mechanisms by which mental fatigue impacts physical function. One theory is an increase in perceived effort in the presence of mental fatigue (Brown & Bray, 2017a; Marcora et al., 2009; Pageaux & Lepers, 2018; Smith et al., 2015). In this theory, it is suggested that mentally fatigued individuals may feel subjectively higher rates of physical exertion during or following bouts of physical activity when compared to individuals not experiencing mental fatigue completing the same bout of physical activity. As such, it is suggested that when individuals are mentally fatigued they may reach a point of voluntary maximal exertion sooner or at lower intensities when compared to individuals who were not mentally fatigued. Another potential theory used to explain the impact that mental fatigue has on perceptual motor task performance is the presence of a speed-accuracy trade-off (Rozand et al., 2015). The speed-accuracy trade-off theory suggests that during periods of internal stress, individuals will subconsciously choose to sacrifice the speed of movement to maintain accuracy, if accuracy is prioritized, or will sacrifice accuracy to maintain speed, if speed is prioritized (Tarr & Nestor, 2011). This theory is particularly pertinent to the study of mental fatigue and perceptual motor accuracy as some recent papers have indicated that individuals will reduce the speed of their movement while throwing darts, likely in a subconscious effort to maintain accuracy (van den Tillaar & Aune, 2019). These two theories provide a significant baseline for future researchers to continue to examine the physiological mechanisms through which mental fatigue impacts physical function.

While it is evident that physical performance is negatively impacted following prior cognitive exertion (Brown et al., 2020), the current understanding of the impact of prior cognitive exertion on perceptual motor tasks, where the primary objective is accuracy, remains limited (McEwan et al., 2013; Rozand et al., 2015). Additionally, research examining potential underlying physiological mechanisms by which mental fatigue reduces physical performance remains limited (Bray et al., 2008; Brown & Bray, 2017; Graham et al., 2014a; Pageaux et al., 2015). Continued research efforts exploring these factors will allow biomechanists and ergonomists to better understand how mental fatigue impacts function and allow for the provision of better accommodations in workplaces and among athletes. As such, the purpose of this study is to examine the impact of mental fatigue on upper limb kinematics and performance accuracy in a novel perceptual motor task requiring aiming performance. The goal of this study is to answer the questions:

1) Does mental fatigue influence accuracy in a novel perceptual motor task?

2) Does mental fatigue lead to a speed-accuracy trade-off during perceptual motor tasks?

3) Does mental fatigue impact the range of motion of important joints utilized in the performance of aiming based throwing tasks?

It was hypothesized that:

1) Mental fatigue would lead to a decrease in performance accuracy.

2) Mental fatigue would lead to a speed-accuracy trade off in favour of maintaining dart throwing accuracy by decreasing movement velocity about the main axis of movement (flexion/extension about the elbow).

3) Mental fatigue would lead to significant changes in the kinematics of the primary upper limb joints utilized within the dart throwing motion.

Chapter 2. The Interactions Between Mental Fatigue and perceptual-motor performance: a Literature Review

2.1 Fatigue

Colloquially, there exists many distinct definitions for the word “fatigue”. In the study of kinesiology, fatigue is often described as a depletion of energy stores resulting in tiredness, brain fog, or muscular weakness. This is often due to a decrease in energy caused by disease or excessive mental or physical exercise (Ishii et al., 2014). The perception of fatigue can be subjective, as definitions can vary from common lay notions of transient muscular weakness or tiredness, to clinically observable conditions such as chronic fatigue (Chaudhuri & Behan, 2004). Many components of daily living can require the use of cognitive or neuromuscular energy and thus can have a fatiguing effect on the individual. As such, it is important to develop an in-depth and universal understanding of the ways in which fatigue can impact individuals. The purpose of this literature review is to examine the impacts of mental fatigue in an effort to answer the following questions:

1) What is mental fatigue?

2) What impacts does mental fatigue have on physical function and performance?

This literature review will touch on the inter-related concepts summarized in Figure 2.1.

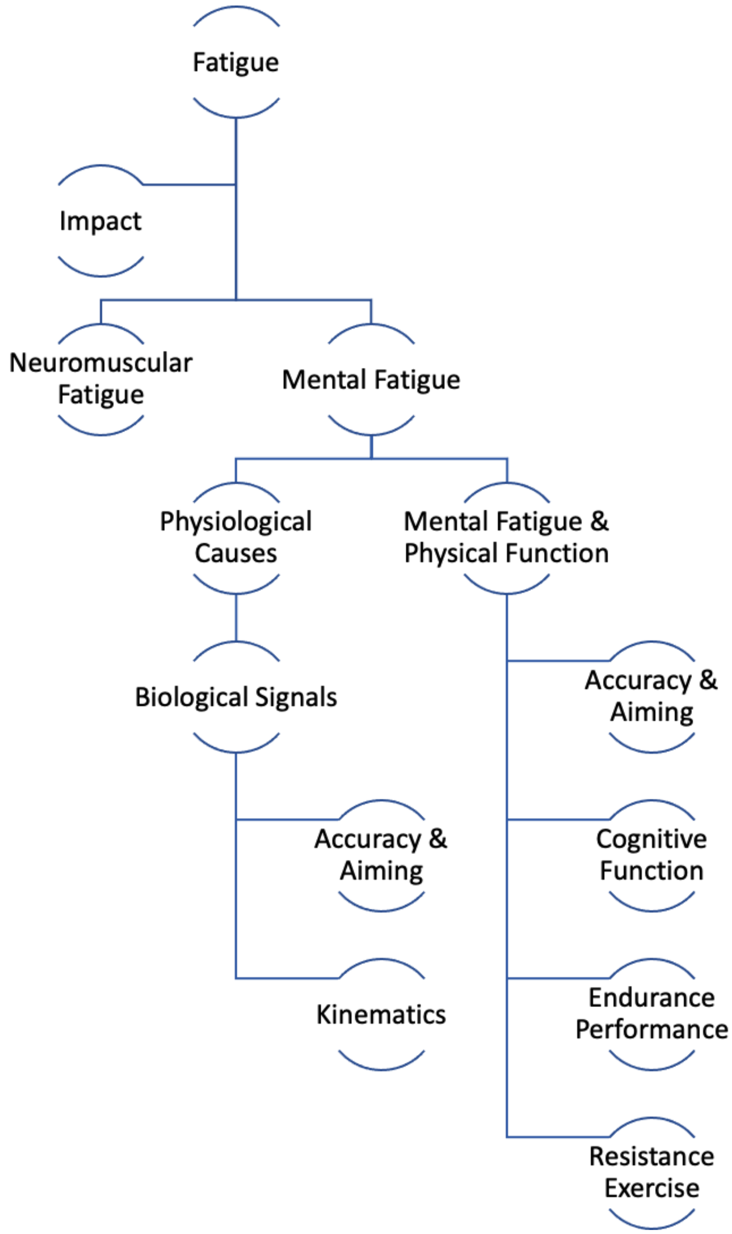

Figure 2.1: Outline of Literature Review

2.1.1 Mental Fatigue

Mental fatigue is a state of reduced function that is caused by extensive use of cognitive energy or control. There are many daily tasks that require the use of cognitive energy or control and can therefore lead to mental fatigue. These tasks include: managing emotions, fixing and maintaining attention, problem solving, making difficult choices, managing or guiding behaviours, and controlling impulses (Baumeister, 2016). As many individuals are required to perform these mental fatigue inducing tasks daily, mental fatigue is commonly experienced.

Many years of research have contributed to the current understanding of the consequences of mental fatigue that exists within the field of neuromechanics. Baumeister (1998) was one of the first to critically examine the physiological consequences of mental fatigue within the field of psychology. In this seminal research, it was suggested that one's subjective sense of cognitive energy can be depleted with extended cognitive exertion and can only be restored following a period of rest. This theory has since been disputed by Marcora (2010) and Noakes (2012) as they identified motivation as a key factor in the magnitude to which mental fatigue impairs cognitive performance. These researchers present evidence that when tasks are highly motivating, task performance is much less likely to decrease in the presence of mental fatigue. Thus, these papers provide strong evidence that mental fatigue is an adaptive process designed to maintain homeostasis by evaluating the energetic cost and potential reward value of completing a task as it relates to the individual's current physiological state. As a result of this research, it is now understood that mental fatigue has significant impacts on both cognitive function and physical function.

Very little is known about the underlying physiological and neurological reasons for the impacts that mental fatigue has on physical and cognitive function. Some researchers suggest that mental fatigue is a beneficial adaptive cognitive and physiological response to allow for the preservation of energy and allocation of appropriate energy reserves only to tasks that are worth the energy expenditure (Boksem & Tops, 2008). It has been suggested that this analysis of energy consumption originates from the orbitofrontal cortex, the basolateral amygdala, the insula, the anterior cingulate cortex, and the nucleus accumbens (Boksem & Tops, 2008) (Figure 2.2). While these findings provide useful insight into the potential mechanisms and consequences of mental fatigue, there is limited empirical data available to allow for the identification of the true underlying neurological and physiological causes and consequences of mental fatigue. It is, however, evident that like neuromuscular fatigue, mental fatigue can act as a protective mechanism to conserve energy in circumstances of energy depletion by signaling the need for rest. Mental fatigue can provide this protective mechanism by reducing cognitive function in response to a fatiguing depletion of cognitive energy (Baumeister et al., 1998). Interestingly, mental fatigue can also provide this protective mechanism by reducing energy expenditure (Boksem & Tops, 2008) in tasks requiring neuromuscular energy (Van Custem et al., 2017). Therefore, it is likely that the consequences, causes, and functional processes through which mental fatigue and neuromuscular fatigue function are highly interconnected. These processes provide protective mechanisms to allow for the maintenance of energetic homeostasis.

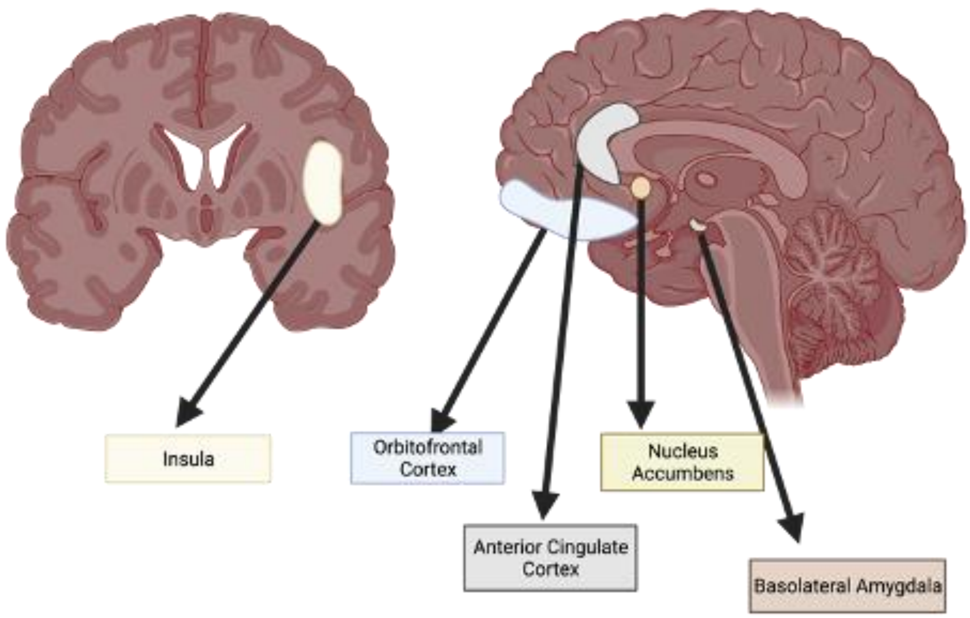

Figure 2.2: Neurological centers associated with the analysis of energy consumption. Licensing information presented in Appendix K.

2.1.2 Neuromuscular Fatigue

To better understand the interconnection between mental fatigue and physical performance, it would perhaps be beneficial to understand the mechanisms underlying neuromuscular fatigue. Neuromuscular fatigue is commonly defined as any physical exercise induced reduction in muscle force or power (Bigland-Ritchie & Woods, 1984). This form of fatigue is often recognizable by symptoms of muscular soreness or weakness. Neuromuscular fatigue is a function of the neuromuscular system and has both central nervous system and peripheral nervous system mechanisms. This form of fatigue is caused by depressions in the function of the neuromuscular system due to overuse or disease (Chaudhuri & Behan, 2004). The neuromuscular system is comprised of the central and peripheral nervous system and its connections to the musculoskeletal system. The neuromuscular system allows for the control of human movement. Signals from the central nervous system allow for specified contractions and relaxations of skeletal muscles to produce precise movements. Within the peripheral nervous system, efferent signals for movement are sent to skeletal muscle fibers through alpha motor neurons (Eccles, 1955; Stifani, 2014). Each alpha motor neuron innervates one or more muscle fibers which are the contractile units of the muscles. An alpha motor neuron along with the muscle fibers that it innervates is known as a motor unit (Liddell & Sherrington, 1925; Sherrington, 1925). The axons of alpha motor neurons attach to muscle fibers via the neuromuscular junction. When alpha motor neuron action potentials reach the neuromuscular junction, the motor neuron releases the neurotransmitter acetylcholine which binds to acetylcholine receptors on the muscle fiber (Stifani, 2014). This binding can cause an action potential to be propagated along the muscle fibre in both directions. This action potential causes the shortening of the sarcomere in accordance with the sliding filament theory (Hugh & Hanson, 1954). As sarcomeres shorten muscles take on shortened positions pulling adjacent bony segments together (Hugh & Hanson, 1954). This allows for the performance of coordinated movements through carefully monitored contractions of agonistic muscle groups (Figure 2.3). It is the complex coordination of the neuromuscular system which allows individuals to perform voluntary movement and it is the depletion of energetic resources within this system which leads to the presence of neuromuscular fatigue.

The neuromuscular system is responsible for the coordination and execution of all skeletal muscular movements, this includes large, generalized, whole body motions and small, precise movements, involving few muscles or muscle groups. As such, the neuromuscular system needs to have the ability to precisely control the location and magnitude of muscular movements and any forces produced by muscular movements. It is therefore important that this system has ways through which force production can be graded to increase or decrease in activated muscles. There are two ways through which the neuromuscular system can provide this power gradient. The first mechanism involves modulation of the firing rate of the alpha motor neuron. This is the speed at which sequential action potentials are sent via the alpha motor neuron to the muscle fibers it innervates in a motor unit (Adrian & Bronk, 1929). As the firing rate of the alpha motor neuron increases, force production increases due to temporal contractile summation. The second method is the recruitment or de-recruitment of additional motor units. The recruitment of additional motor units into a contractile force allows for the activation of additional muscle fibers resulting in increased force production, whereas de-recruitment decreases force production (Adrian & Bronk, 1929). There is some selectivity in the order in which additional motor units are recruited with smaller motor units often being recruited first followed by larger motor units (Hennemn et al., 1964). Together, these recruitment and de-recruitment processes allow the neuromuscular system to coordinate complex movement.

Proprioception and sensory inputs are also incredibly important components of the neuromuscular system as they allow for the integration of movement within its environment. Proprioception is the process through which individuals can evaluate the body's position and accuracy of movement (Proske & Gandevia, 2012). When interrupted, these inputs can dramatically change movement accuracy (Boksem & Tops, 2008). Studies have suggested that mental fatigue might down regulate various components of this neuromuscular system, thus dramatically changing the accuracy of an individual's movement (Boksem & Tops, 2008; Ishii et al., 2014). This research provides interesting insights into the significant impacts that mental fatigue might have on the neuromuscular system and suggests that mental fatigue and neuromuscular fatigue might share similarities in their interactions with the neuromuscular system.

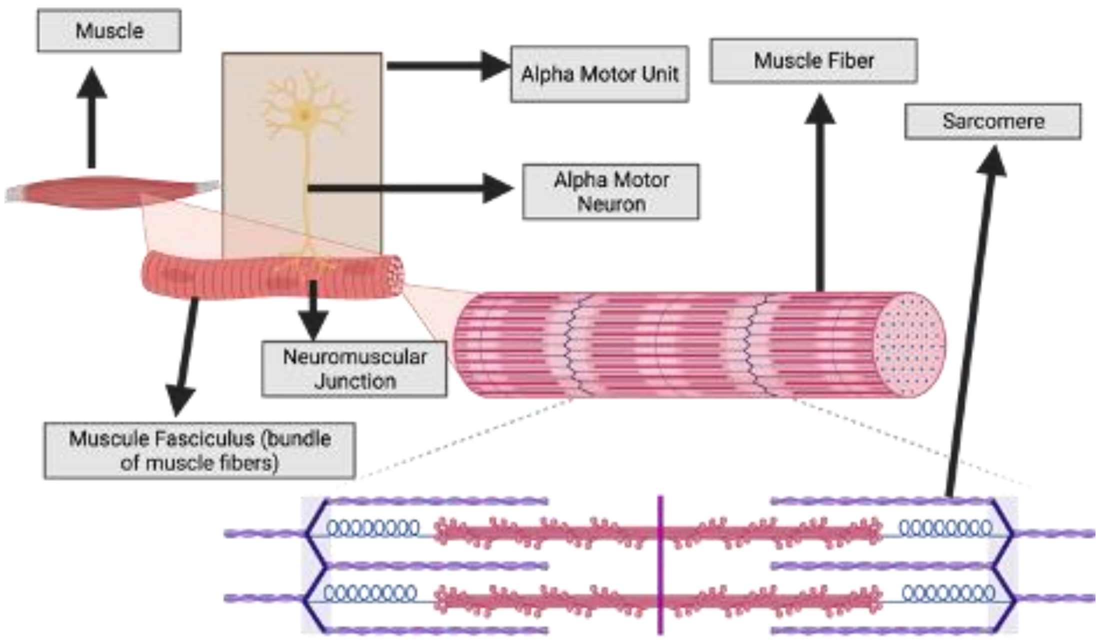

Figure 2.3: Diagram of the neuromuscular system. Licensing information presented in Appendix K.

2.2 Impacts of Mental Fatigue

While the subjective experiences of mental fatigue and neuromuscular fatigue are often distinctly unique, it is likely that these forms of fatigue are highly interconnected. To appreciate this connection, it is important to first examine the significant impacts that mental fatigue can have on cognitive and physical function.

2.2.1 Mental Fatigue and Cognitive Impacts

Mental fatigue reduces the ability to perform tasks that require cognitive energy or control and reduces the ability to endure mental tasks (Chaudhuri & Behan, 2004). This phenomenon is well documented in the literature with many studies consistently demonstrating a decrease in performance on tasks that require cognitive control following the depletion of cognitive energy (Alder et al., 2021; Baumeister et al., 2016; Baumeister et al., 1998; Baumeister et al., 2007). Furthermore, it has been suggested that mental fatigue induced by any activity that requires cognitive energy or control reduces performance in all tasks that require cognitive energy or control regardless of the type of cognitive energy that the task requires (Baumeister, 2016). This concept was first explored in a series of experimental trials during which researchers investigated the impacts of cognitive depletion from a variety of tasks on performance in a variety of subsequent cognitive tasks. This series of trials provided evidence that performing a task that required impulse control and resisting temptation, a task that required emotional control, or a task that required emotional suppression all reduced cognitive endurance when attempting to solve a puzzle with no possible solutions (Baumeister et al., 1998). The results of this publication allowed for the common conclusion: the performance of a cognitively depleting task, regardless of the task type, reduces cognitive performance in any tasks that require cognitive energy or control.

This discovery allowed for the development of several standardized cognitive tasks that have been used in experimental settings to induce mental fatigue. The incongruent Stroop task (Stroop, 1935) is a prominent example of one such cognitive task. There are two versions of the Stroop task that are commonly used in the study of mental fatigue. When performing the incongruent version of the Stroop task, participants are presented with a series of colour words in a coloured font that differs from the colour word presented. For example, the word red might be presented in blue font. In this task, participants are asked to identify the colour of the font presented instead of reading the word. The incongruent Stroop task induces fatigue as participants are required to quickly identify the colour word while ignoring the colour of the font in which it is presented, a task that requires cognitive energy. When performing a congruent Stroop task, participants are presented with a series of colour words with a font colour identical to the colour word. For example, the word red spelled in a red font. In this task, participants are asked to identify the colour of the word that they have been presented. This version of the Stroop task was designed with the explicit goal of not inducing mental fatigue and is designed as a control task in mental fatigue research. The congruent version of the Stroop task is one prominent example of a cognitively and emotionally neutral control task that can be used in the experimental study of mental fatigue. Another common control task is the viewing of an emotionally neutral and cognitively neutral movie or documentary (Marcora et al., 2009). The Stroop task and other similar cognitive tasks are often used within research, to examine the impact that mental fatigue has on cognitive function (Brown et al., 2020).

2.2.2 Mental Fatigue and Physical Endurance

Mental fatigue has been demonstrated to have a significant impact on tasks involving muscle or cardiovascular endurance. In a recent meta-analysis, Brown et al. (2020) examined 73 mental fatigue studies and found evidence that mental fatigue, induced through prior cognitive exertion, significantly reduces isometric, resistance, and aerobic endurance performance. Similarly, another recent meta-analysis by Giboin and Wolff (2019) indicated that mental fatigue significantly reduced endurance performance regardless of the specific endurance activity that was being performed. These results have been supported in other recent literature (Cutsem et al., 2017; Pageaux & Lepers, 2018). Interestingly, some recent literature has indicated that the negative impacts that mental fatigue has on physical performance seem to only be observed at submaximal intensities (Brown et al., 2020; Pageaux & Lepers, 2018). This evidence indicates that mental fatigue impacts aerobic and submaximal exercise endurance capacity at a much greater and more significant rate than maximal and anaerobic performance. Interestingly, recent evidence has indicated that mental fatigue may have a larger negative impact on endurance exercise involving few muscles or muscle groups than on whole body endurance exercise (Giboin & Wolff, 2019). Further research examining this phenomenon is required for researchers to better understand the implications of these findings.

2.2.3 Mental Fatigue and Resistance Exercise

While the negative impacts that mental fatigue have on endurance performance have been demonstrated consistently throughout the literature, the impacts that mental fatigue have on acute muscular strength have less consistent results. Much recent literature has indicated a significant decrease in isometric resistance, dynamic resistance, and motor performance associated only with mental fatigue when mentally fatiguing tasks lasted 30 minutes or less. While many papers found that mental fatigue, induced through tasks lasting 30 minutes or longer, significantly negatively impacted aerobic and motor performance while having no impact on isometric resistance or dynamic resistance

(Brown et al., 2020; Cutsem et al., 2017). However, it has been indicated that these results should be interpreted with caution as there are few studies examining isometric or dynamic resistance following a mentally fatiguing task of longer than 30 minutes (Brown et al., 2020). This provides an interesting opportunity for future researchers to explore the relationship between isometric or dynamic resistance and mental fatigue induced through cognitive tasks lasting longer than 30 minutes.

2.2.4 Mental Fatigue, Accuracy and Aiming

Mental fatigue seems to not only impair physical endurance and strength, but also performance in perceptual motor tasks. One study saw a decrease in mean accuracy and consistency of accuracy of dart throws in a post mental fatigue trial compared to a non-mentally fatigued control (McEwan et al., 2013). However, other studies have shown no such changes in accuracy associated directly with mental fatigue (Englert & Bertrams, 2012; Head et al., 2017). One such paper examined the effects of mental fatigue on accuracy in perceptual motor tasks. This study involved trained military personnel from the United States Army and measured marksmanship accuracy before and after a mentally fatiguing task. No change in accuracy was noted in association with mental fatigue in this study (Head et al., 2017). This study did, however, demonstrate some changes in marksmanship performance. Participants in this study were presented with active targets, which they were expected to shoot, and decoy targets, which they were expected not to shoot. When mentally fatigued, participants were more likely to shoot a decoy target than in the non-mentally fatigued control (Head et al., 2017). In another similar study (Rozand et al., 2015), participants were expected to move their hand between two targets in an alternating repetitive motion; if two consecutive targets were missed, the trial would be cancelled. There was a significant increase in cancelled trials when participants were mentally fatigued when compared to the control trial. This study demonstrated other significant results. While accuracy was maintained by participants, the time it took participants to perform these motions increased in the presence of mental fatigue. The researchers indicated that it was likely that participants changed their movement speed as a strategy from the central nervous system to maintain accuracy (Rozand et al., 2015). It has been suggested that when participants are mentally fatigued, biomechanical performance is altered (Pageaux & Lepers, 2018). The evidence presented above suggests that mental fatigue has a marginal impact on performance accuracy in perceptual motor tasks. However, mental fatigue seems to be more likely to impact the timing and biomechanical processes through which these tasks are performed than aiming accuracy in task performance. Additional research investigating the impacts of mental fatigue on perceptual motor tasks involving aiming would allow for a more precise understanding of the impacts that mental fatigue have on perceptual motor tasks and their underlying neuromechanical mechanisms.

2.3 Physiological Causes

To better understand the significant impacts that mental fatigue can have on physical function, and the connection between mental fatigue and neuromuscular fatigue, it is important to explore some of the probable physiological mechanisms through which mental fatigue impacts physical functioning. Results from several recent studies seem to suggest that mental fatigue does not significantly impact any physiological functions typically associated with decreases in endurance including cardiac output, blood lactate, oxygen uptake, heart rate, and blood glucose consumption (Cutsem et al., 2017; Smith et al., 2015). However, it is suggested that the reduced endurance associated with mental fatigue is a result of an increase in ratings of perceived exertion. This indicates that when mentally fatigued, physical performance is potentially decreased as a result of increases in perceived effort to maintain task performance which, in turn, results in reductions in physical performance. In this theory, it is suggested that mentally fatigued individuals may feel subjectively higher rates of physical exertion during or following bouts of physical activity when compared to individuals not experiencing mental fatigue completing the same bout of physical activity. As such, it is suggested that when individuals are mentally fatigued they may reach a point of voluntary maximal exertion sooner or at lower intensities when compared to individuals who were not mentally fatigued. As a result of increases in perceived effort to maintain task performance when mentally fatigued, physical performance is potentially decreased (Cutsem et al., 2017; Marcora et al., 2009; Pageaux & Lepers, 2018; Smith et al., 2015).

2.4 Perceptual-Motor Tasks

The lack of research examining the impacts of mental fatigue on perceptual-motor tasks, commonly known as accuracy and aiming based tasks, presents an interesting challenge for researchers studying mental fatigue. The impact that mental fatigue has on accuracy and aiming based tasks is arguably the least well-documented physical performance parameter. These accuracy-based tasks require a complex integration and exchange of information between the portions of the nervous system responsible for perception and the neuromuscular system. These tasks are common in daily functions. Some activities that utilize perceptual-motor integration might include: walking on uneven surfaces, pressing buttons or pointing to objects, throwing and catching balls or throwing darts.

Dart throwing and other similar activities allow for a unique and interesting perspective on aiming activities involving perceptual motor integration. This is because activities like dart throwing are controlled with well-defined and universally measurable performance outcomes. As such, dart throwing is an ideal perceptual-motor task to observe in an experimental setting.

2.5 Perceptual-Motor Variables of Interest

There are two areas of interest in which mental fatigue might have a direct and detectable impact on tasks requiring perceptual-motor integration. These areas are performance accuracy and kinematic behaviour.

2.5.1 Accuracy

Accuracy is likely the most common and least complex experimental method through which performance in perceptual-motor tasks can be measured. Accuracy has been defined as a performance measure which represents the degree to which the target was not achieved, this is therefore a measure of error (Schmidt et al, 2019). Accuracy is a critical component of successful dart performance, where players are aiming for specific targets on the dart board. Darts can also be used in experimental settings to measure accuracy. In this sport, accuracy can be easily graded based on the individual’s ability to have the thrown dart lodge into the dart board as close as possible to the center of the target (i.e. the bullseye). Accuracy performance in a round of dart throwing can be determined based on the culmination of points assigned to each dart thrown, with darts landing in the bullseye given full points and darts landing on rings outside of the bullseye gaining progressively fewer points as a factor of their distance from the bullseye. The easily measurable performance parameters make darts ideal for the experimental measurement of accuracy-based movement. For this reason, dart throwing has been used in prior studies examining the impacts of mental fatigue on perceptual-motor tasks (Englert & Bertrams, 2012; McEwan et al., 2013).

While some studies have provided evidence that mental fatigue can decrease accuracy in perceptual motor tasks (McEwan et al., 2013), these results are inconsistent within the literature with some studies showing no impact of mental fatigue on performance accuracy (Englert & Bertrams, 2012; Head et al., 2017). Therefore, additional research would provide useful insight into the impact of mental fatigue on accuracy performance.

2.5.2 Kinematics

Assessment of human motion kinematics provide significant insights into the impacts of various stimuli on human movement. The measurement of human kinematics can be accomplished through the use of specific kinematic transducers such as inertial sensors, gyroscopes, accelerometers, electromagnetic systems, and optical kinematics systems. The basic function of each of these motion capture approaches is to track the movement of body segments during human motion, with commonly reported kinematic variables being time-series representations of joint angles or their underlying change over time (e.g. velocity and acceleration). These tools provide valuable insight into the functioning of the neuromuscular system by allowing researchers to monitor movement patterns.

Interesting kinematic findings have been observed at the joint level in response to localized muscle fatigue. For example, Huffenus et al. (2005) conducted a study that had participants perform disk throwing tasks following either fatiguing of the distal throwing limb or proximal throwing limb. When fatigued, participants modified their movement patterns while performing disk throws. When distal fatigue was present, participants maintained wrist angular velocity by decreasing elbow torque. However, when the proximal arm was fatigued, increased contributions were observed from the wrist. This adjustment in joint kinetics and kinematics supports a concerted neuromechanical strategy to maintain performance accuracy despite a fatigue-based perturbation to the system. In explaining these results, the authors cite Dounskaia et al. (1998) and Bernstein et al. (1996), who suggested that in movements that require multi-joint integration, there exists a hierarchical control of the joints. In this hierarchy, the role of the proximal joint is to generate the movement and the role of the distal joint is to adjust the movement based on the task goal. It is possible that muscular fatigue can lead to the reorganization of motor control to allow for the maintenance of movement while compensating for reduced function in the fatigued muscles. It was suggested that in states of muscular fatigue, the central nervous system can use feedforward control to differently adapt multi-joint movements to maintain task function (Huffenus et al., 2005). In this paper, this adaptation from the central nervous system resulted in a consistent hand trajectory regardless of neuromuscular fatigue status. These findings suggest the presence of complex biomechanical adaptations in response to neuromuscular fatigue.

Other previous research has provided additional evidence that neuromuscular fatigue can significantly impact kinematic behaviour, especially during tasks that require accuracy. The impacts of neuromuscular fatigue often manifest in the accuracy and speed of movement tasks (Tarr & Nestor, 2011). This concept was demonstrated in a study during which participants were asked to push a low load back and forth along a track until volitional exhaustion. In this study, muscular fatigue significantly changed the participants' kinematic behaviour. The authors attributed these findings to the "speed-accuracy trade off", where individuals adjust timing and accuracy to allow for the maintenance of the component that is deemed more relevant to the task when energy reserves are compromised (Gates & Dingwell, 2008). Interestingly, the speed-accuracy trade-off theory has not presented consistent results across all current literature. For example, one study attempted to explore this theory by manipulating whether participants focused on dart throwing speed or dart throwing accuracy. While this study observed no significant differences in mean radial error when participants were instructed to focus on speed over accuracy, a significant decrease in bivariate variable error was observed during speed focused trials. Bivariate variable error was defined as the absolute distance of the subject's midpoint to the bullseye, with the subject's midpoint being defined as the average dart landing location for each dart throwing trial (van den Tillaar & Aune, 2019). Considering this evidence, it appears that when both speed and accuracy are constrained, accuracy tends to be prioritized.

The speed-accuracy trade off theory has been further demonstrated in studies examining the impact of mental fatigue on kinematic performance. In one study it was found that participants increased their task movement time in an effort to maintain accuracy while mentally fatigued (Rozand et al., 2015). This suggests that mental fatigue has impacts which are similar to whole-body neuromuscular fatigue on kinematic movement and potentially acts through similar physiological and neuromechanical pathways to influence the speed-accuracy trade-off. This research indicates a complex relationship between mental fatigue and biomechanical movement.

The next logical question to pose is: does the influence of mental fatigue on the speed accuracy trade-off transfer to pure performance accuracy (when speed is not considered)? The literature seems to suggest that mental fatigue has only a minimal impact on accuracy when speed of movement is not involved in task performance. This concept was well exemplified in a randomized control trial during which the marksmanship performance of participants was observed before and after mental fatigue protocols. This study demonstrated evidence that mental fatigue did not negatively impact marksmanship accuracy, likely due to a speed accuracy trade-off performed by participants when mentally fatigued, to maintain the aspect of the tasks that was deemed more important - in this case, that aspect being task accuracy. However, this study also produced some other interesting results as researchers observed a significant increase in participants firing their guns during times when they were not told to fire, along with a significant increase in missed signals to fire (Head et al., 2017). This concept is likely relevant to any activity that requires perceptual-motor accuracy such as marksmanship, pitching or dart throwing.

2.6 Purpose of Thesis

Considering the information presented above, it is evident that the consequences of mental fatigue on physical function have similarities to those observed during neuromuscular fatigue. The impacts of neuromuscular fatigue on physical function are well recognized and often accounted for in the planning of workplace tasks. As many workplaces require individuals to utilize both mental and neuromuscular energy, it is important to understand the ways in which these forms of fatigue can impact function and performance. As researchers expand their understanding of the physical consequences of mental fatigue, and its similarity to neuromuscular fatigue, employers will be able to develop evidence-based methods through which to encourage mental rest and reduce the negative impact that mental fatigue can have on physical function in the workplace. Additionally, coaches and trainers might benefit from the availability of a more comprehensive understanding of the physical consequences of mental fatigue to aid in the development of training protocols to account for mental fatigue.

Chapter 3.0 The Impacts of Mental Fatigue on Dart Throwing Performance

3.1 Methods

3.1.1 Participants

40 participants were recruited from within the undergraduate and graduate population at Ontario Tech University (N=40; 20 male, 20 female). Participants were randomly assigned to the mental fatigue condition (N = 20, 10 male, 10 female, M_{age} = 21.4 years, SD_{age} = 3.07 years) or the control condition (N = 20, 10 male, 10 female, M_{age} = 20.2 years, SD_{age} = 5.34 years). Participants were randomized into these groups stratified by sex. A formal sample size calculation using G*Power 3.1.9.2 (Faul et al., 2009) based on a medium effect size for motor-based task performance following mental fatigue (i.e., f = 0.25, Brown et al., 2020) with power = 0.80, α = 0.05, indicated a sample of N = 34 would be sufficient for repeated measures ANOVA analysis (within-between interaction).

All participants were adults between the ages of 18-30. Participants were excluded from the study if they had played darts beyond a recreational level, required prescription glasses for everyday use without the ability to wear prescription contact lenses, or were colour blind. Additionally, individuals with any injuries/symptoms that may prevent completion of a cognitively challenging task and/or up to 60 dart throws in one sitting were excluded. Ethics approval was provided by University of Ontario Institute of Technology's (Ontario Tech University) Research Ethics Board. All participants provided signed informed consent prior to data collection (Appendix D). Undergraduate participants received 0.25% extra credit in undergraduate courses for each hour spent participating in this study.

3.1.2 Instrumentation

3.1.2.1 Darts and Dart Board Instrumentation

Participants used regulation steel tip darts (weight of 22 grams). Participants stood on a force platform elevated 10 centimeters (cm) above the ground. The dart board had a diameter of 451 millimeters (mm) and was located 2.37 meters (m) from the throwing line with the centre of the board located 1.73 m above the platform on which participants stood (1.83 m above the ground) (Figure 3.1). The dartboard and darts used were set up based on the described set up in a study by Englert and Bertrams (2012). Participants were told to aim for the centre (or "bullseye") of the dart board and a dart throwing performance score was assigned based on mm accuracy from the centre of the bullseye of the dart board. Following measurement of dart location, darts were removed from the dart board by a researcher and returned to the participant to continue the dart throwing trial (Figure 3.2).

Figure 3.1: Image of dart board face

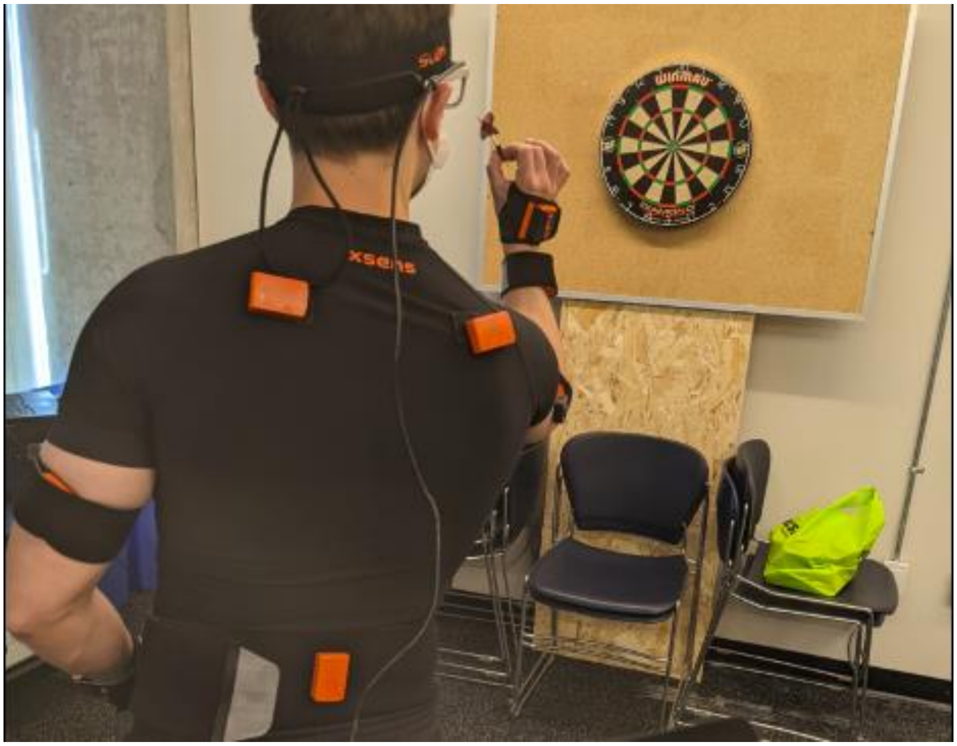

Figure 3.2: Image of experimental set up

3.1.2.2 Motion Capture and Imaging Instrumentation

Kinematic data were captured using Xsens MTw Awinda Inertial Motion Capture System (Xsens, Xsens Technologies BV, Enschede, The Netherlands) and MVN Analyze software (Xsens, Xsens Technologies BV, Enschede, The Netherlands). Kinematic data were sampled at a frequency of 60 hertz (Hz). The global reference coordinate system was organized such that +Y was directed upwards and parallel to the field of gravity, +X was located in the horizontal plane in the direction of throwing and +Z was located on the horizontal plane perpendicular to the X. The origin of the global coordinate system of each segment of interest was located at the approximate centre of mass (CoM) of the associated segment with + Y being in the proximal direction, +X being in the anterior direction, and +Z being defined by the right-hand rule with reference to anatomical position. These local and global coordinate systems were defined according to the

International Society of Biomechanics (ISB) standard conventions (Wu & Cavanagh, 1995).

Joint angular velocity was monitored from each participant's wrist, elbow, and shoulder during each dart throwing trial using this motion capture system. MTw inertial measurement sensors were used to collect joint angular velocity. These sensors contained a rate gyroscope which allowed for the collection of 3D angular velocity data, an accelerometer which allowed for the collection of 3D acceleration data, a magnetometer which allowed for the collection of 3D data indicating of surrounding magnetic fields, and a barometer which allowed for the collection of data indicating atmospheric pressure. One MTw inertial measurement sensor was secured to segments of interest using Velcro straps or self adhesive tape. The segments of interest included the hand (MTw sensor affixed to back of the hand at the proximal 1/3 distance from the styloid process of the radius and the ulna to the 2nd metacarpophalangeal joint), the forearm (MTw sensor affixed directly above the styloid process of the radius and the ulna on the back of the forearm), the upper arm (MTw sensor affixed on the lateral side of the upper arm between the muscle groups of the biceps and the triceps at the proximal 1/3 distance from the acromion to the midline of the medial and lateral humeral epicondyles) and the shoulder (affixed at the proximal 1/2 distance between the 7th cervical vertebra and the acromion using self adhesive tape).

Dart landing locations were captured using still images taken from a standardized location using the Canon PowerShot ELPH 190 IS (Canon Inc, Tokyo, Japan) digital camera with images taken at approximately 20.0 megapixels.

3.1.2.3 Experimental Manipulation Instrumentation

A ten-minute incongruent Stroop task was used in the mental fatigue condition (Stroop, 1935; Wallace & Baumeister, 2002). During the performance of the incongruent Stroop task, participants were presented with a series of printed text consisting of a list of colours printed in incongruent ink colours as seen in Figure 3.3. Participants were asked to verbally identify the ink colour for each word in their listed order, with the exception of any words printed in red ink for which they were asked to read the word (i.e. the word “blue” printed in yellow ink would be correctly identified as “yellow”, however, the word “blue” printed in red ink would be correctly identified as “blue”). The control manipulation consisted of a ten-minute viewing of an emotionally neutral clip from the documentary; Our Planet (Fothergill, 2019).

Figure 3.3: Image of an example portion of an incongruent Stroop task

3.1.3 Secondary Outcome Measures

The NASA task load index (NASA-TLX) was used to measure subjective workload during the performance of each of the dart throw clusters (Hachard et al., 2020) and was assessed following each of the dart throw clusters. This measurement tool evaluates contributions from a series of potential workload sources including mental demand, physical demand, temporal demand, performance, effort, and frustration. The mental demand item was evaluated using the question "How mentally demanding was the task?" graded from "Very Low" at 0 to "Very High" at 21. The physical demand item was evaluated using the question "How physically demanding was the task?" graded from "Very Low" at 0 to "Very High" at 21. The temporal demand item was evaluated using the question "How hurried or rushed was the pace of the task?" graded from "Very Low" at 0 to "Very High" at 21. The performance item was evaluated using the question "How successful were you in accomplishing what you were asked to do?" graded from "Failure" at 0 to "Perfect" at 21. The frustration item was evaluated using the question "How insecure, discouraged, irritated, stressed and annoyed were you?" graded from "Very Low" at 0 to "Very High" at 21 (Appendix F).

A one-item mental fatigue visual analog scale was used to assess perceptions of mental fatigue during the experimental manipulation. This scale is consistent with that described in the study by Brown and Bray (2017). This measurement tool consisted of one item evaluated using the statement "please mark an X on the line at the point that you feel represents your perception of your current state of mental fatigue" and was answered on a one-hundred-point scale ranging from 0 (none at all) to 100 (maximal). Mental fatigue was assessed at 2-minute intervals during the experimental manipulation

(Appendix I). Task success was evaluated concurrently by researchers using a grading sheet which indicated correct responses (Appendix E). Researchers marked each individual correct and incorrect response given, but these data are not presented in this thesis and may be considered for a secondary analysis outside the scope of this work.

Consistent with previous research (Graham et al., 2018), the Intrinsic Motivation Inventory (IMI) effort and importance subscale (5-items) (Ryan, 1982) was used to assess motivation, prior to each dart throw cluster. Items in this subscale include; “I am going to put a lot of effort into this task.”, “I am going to try very hard to do well at this task.”, “I am going to try very hard on this task.”, “It is important to me to do well at this task.”, and “I am going to put a lot of energy into this task.”. Participants were asked to rate each item on a scale ranging from 1 to 7 with 1 indicating that the statement was “Not at all true”, 4 indicating that the statement was “Somewhat true” and 7 indicating that the statement was “Very true” (Appendix G).

A task self-efficacy scale (TSES) was used to measure task self-efficacy before the second dart throwing trial. This measurement tool consisted of one item (“How confident are you in your ability to throw the darts more accurately than last time?”) answered on a 11-point scale from 0 (not confident at all) to 10 (totally confident) (Appendix H).

The brief version of the trait self-control scale (BTSCS) was used to measure participant’s self-identified trait self-control following experimental protocol. This measurement tool consists of 13 items answered on a 5-point scale ranging from 1 (not at all like me) to 5 (very much like me) (Tangney et al., 2004). Items presented in this survey include; 1.“I have a hard time breaking bad habits”, 2. “I am lazy”, 3. “I say inappropriate things”, 4. “I do certain things that are bad for me if they are fun”, 5. “I refuse things that are bad for me”, 6. “I wish I had more self-discipline”, 7. “People would say that I have iron (strong) self-discipline”, 8. “Pleasure and fun sometimes keep me from getting work done”, 9. “I have trouble concentrating”, 10. “ I am able to work effectively toward long-term goals”, 11. “Sometimes I can’t stop myself from doing something, even if I know it’s wrong”, 12. “I often act without thinking through all the alternatives”, and 13. “I am good at resisting temptation” (Appendix J).

3.1.4 Experimental Procedure and Protocol

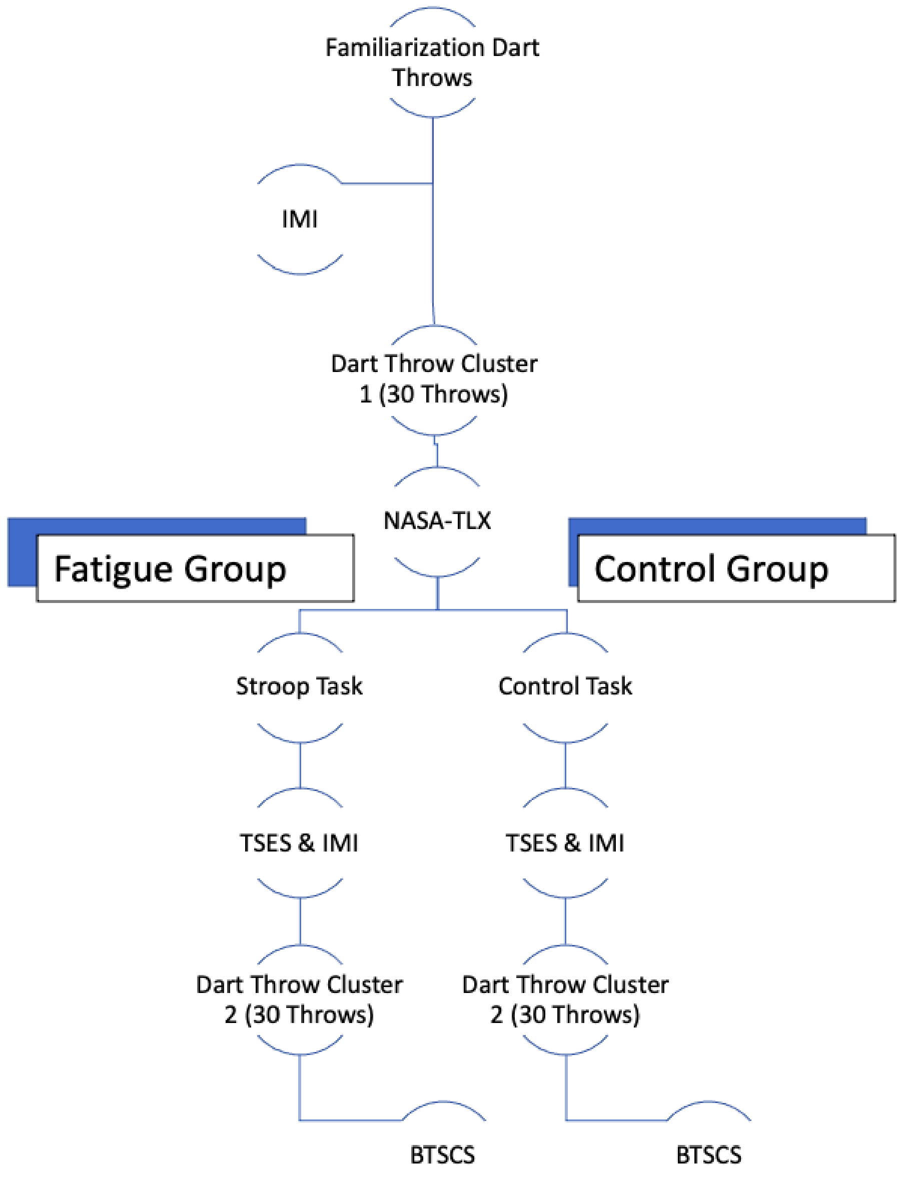

Figure 3.4: Experimental Protocol including intrinsic motivation inventory scale (IMI), the NASA task load index (NASA-TLX), the task self efficacy scale (TSES), and the brief trait self-control scale (BTSCS).

3.1.4.1 Demographic Information and Calibration

Participant's demographic information (age, sex, upper arm injury history, vision strength, and previous dart experience) were pre-screened using the demographic information questionnaire presented in Appendix C. This pre-screening was conducted via email correspondence following participant recruitment during which participants were sent the informative email presented in Appendix B. Upon arrival, participants were briefed on experimental protocol and instrumental calibration occurred. MTw inertial sensors were affixed to their associated segments of interest and calibration of the Xsens motion capture system was performed.

3.1.4.2 Dart Throwing Acclimation Trial

Participants threw three mock dart throws, during which they mimicked the dart throwing motion while holding a dart to ensure that the motion capture system was not affixed to any segments in a position that would interfere with dart throwing motion. If the motion capture system was found to interfere with motion, it was adjusted and recalibrated. Following acclimation dart throws, participants completed the IMI questionnaire.

3.1.4.3 Dart Throw Cluster 1

Participants then performed the first experimental dart throwing cluster. During this dart throwing cluster, participants were provided with three darts and performed a dart throwing cluster consisting of ten rounds of three dart throws resulting in 30 total dart throws. Each dart used was identifiable by a differently coloured flight with one dart having a bright green flight, one dart having a bright red flight and one dart having a bright blue flight. Participants were asked to throw the darts in the following order: green first, followed by red, followed by blue, participants were reminded of this dart throwing order prior to each dart throwing set. During dart throws, participants were asked to stand within a demarcated square of 500mm by 500mm at a standardized distance from the dart board. Participants were instructed to position their feet and bodies however felt most comfortable to them. Participants were asked to begin each dart throwing set with their arms still and by their sides, participants were asked to avoid shifting their feet during dart throwing sets. Participants were reminded of these specifications prior to each dart throwing set. Between each set of dart throws, a researcher retrieved the thrown darts and returned them to the participant to be used in the following round. Prior to the darts being returned to the participant, an image of the dart board and locations of each of the 3 darts thrown during each set was taken. Following this first dart throw cluster, participants completed the NASA-TLX questionnaire.

3.1.4.4 Experimental Manipulation

Participants then completed the 10-minute mental fatigue or control manipulation. The mental fatigue manipulation consisted of a ten-minute incongruent Stroop task (Stroop, 1935; Wallace & Baumeister, 2002). The control manipulation consisted of a ten-minute viewing of an emotionally neutral clip from the documentary; Our Planet (Fothergill, 2019). Throughout this experimental manipulation, the mental fatigue visual analog scale was administered at intervals of 2 minutes with the first assessment being completed prior to the beginning of the intervention and the final assessment being completed at the 10 minute interval. The TSES questionnaire was completed immediately following the completion of the experimental intervention followed by the completion of the second IMI questionnaire.

3.1.4.5 Dart Throw Cluster 2

Participants then completed the second dart throwing cluster following the same protocol as dart throwing cluster 1. Each participant began the second dart throwing cluster 3 minutes following the termination of the experimental intervention. Following this final dart throw cluster, participants completed the second NASA-TLX questionnaire followed by the completion of the BTSCS questionnaire.

3.1.4.6 Overview of Experimental Protocol

Joint angle motion capture was collected for the duration of each dart throw from the initiation of movement to when participants released the dart. Dart location motion capture data was collected following each round of three dart throws. The experimental protocol was consistent with previous research (McEwan et al., 2013). Please refer to Figure 3.4 for a visual graphic depicting the experimental protocol used.

3.1.5 Data Analysis

3.1.5.1 Dart Accuracy Data

Images taken of each dart throwing set using the Canon PowerShot ELPH 190 IS camera were used to determine dart landing location. Dart order was identified using the colour of the dart flights. The coordinates of dart landing locations, bullseye location along with a location along the outer ring of the dart board were identified in pixels with the origin being set to the top left corner of each individual image. A pixel to mm conversion factor was created using each individual image's pixel distance between the bullseye and the outer ring of the dart board and the understanding that the radius of the dart board was 225.5 mms. Each dart's pixel distance from the bullseye in the horizontal and vertical planes were determined and were converted to mm distance using the calculated conversion factor. Both horizontal and vertical distance from the bullseye measured in mm were treated as dependent variables, as was the Euclidean (resultant) distance. resultant error from the bullseye was determined using Eq. 3.1.

$$[\text{Eq. 3.1}]\ \text{Resultant Error} = \sqrt{\text{Horizontal Distance}^{2} + \text{Vertical Distance}^{2}}$$

Dart throw recalibration was used to identify each participant's ability to recalibrate dart throwing accuracy in the second half of each dart throwing cluster based on dart throwing accuracy in the first half of the dart throwing cluster. Recalibration rate was calculated using Eq. 3.2.

[Eq. 3.2] Recalibration Rate = Resultant Error (throw 1:15) - Resultant Error (throw 16:30)

3.1.5.2 Motion Capture Data

Angles, angular velocities, and accelerations of joints and segments of interest were computed by the Xsens analysis software (Xsens, Xsens Technologies BV, Enschede, The Netherlands) according to the ISB convention. All joint angles were expressed in degrees relative to anatomical position. Two events of interest were extracted: retraction angle and end of movement angle. Moment of retraction was defined as the moment of deepest elbow flexion and moment of end of movement was defined as the movement of highest elbow extension during each dart throw (Figure 3.5). Moment of retraction and moment of end of movement were extracted manually from each dart throwing set using a custom made LabVIEW program. Shoulder horizontal adduction/abduction and angle of elevation, elbow flexion/extension, and wrist ulnar/radial deviation and flexion/extension angles at the moment of retraction and the moment of end of movement in the dominant arm were extracted. Throw time was calculated using Eq. 3.3.

[Eq. 3.3] Throw Time = Time at end of movement – Time at full retraction

Angular velocity overthrow duration was calculated for the shoulder in the horizontal adduction/abduction direction and the angle of elevation direction, for the elbow in the flexion/extension direction, and for the wrist in the flexion/extension direction and the ulnar/radial deviation direction. Velocities were calculated using Eq. 3.4.

[Eq. 3.4] Velocity = (End of movement joint angle - Retraction angle)/Throw Time

Preparation time (prep-time) was defined as time between dart throws in a set and was calculated using Eq. 3.5.

[Eq. 3.5] Prep-Time = Moment of retraction - moment of end of movement of previous dart throw

Figure 3.5: Image of example full retraction angle and end of motion angle note: participants were wearing eye tracking goggles for another study not relevant to this thesis.

3.1.5.3 Secondary Outcomes

IMI score was reported as the mean of each of the 5 item scores. Subscales of the NASA-TLX were reported independently. The BTSCS was reported as the sum of all items with items 1, 2, 3, 4, 6, 8, 9, 11, and 12 being reverse scored and a higher total score indicating higher levels of trait self-control. Individual values on the TSES were reported independently. Mental fatigue scores were obtained by averaging the mental fatigue scores from each of the 0 minute, 2 minute, 4 minute, 6 minute, 8 minute, and 10 minute time points for each individual participant.

3.1.6 Statistical Analysis

3.1.6.1 Primary Outcome Measures

IBM SPSS statistical analysis software was used to perform all statistical analyses. Where possible, repeated measures 2 (group) x 2 (time) ANOVAs and one-way ANOVAs were used in the statistical analysis of dependent variables with groups being defined by the participant's assigned condition (control or fatigue) and time being defined as time of dart throw set (pre or post intervention). Dependant variables in these analyses include accuracy variables, time variables, and joint kinematic variables. Accuracy dependant variables include horizontal and vertical accuracy relative to the bullseye, resultant accuracy relative to the bullseye, and recalibration rate. Joint kinematic dependant variables include retraction angles, end of movement angles, and mean velocities for the shoulder in the horizontal adduction/abduction, and angle of elevation directions, the elbow in the flexion/extension direction, and the wrist in the ulnar/radial deviation and flexion/extension directions. Time dependant variables include throw time and preparation time. Significance was set to $p < 0.05$ in all cases in which ANOVAs were used.

Shapiro-Wilks along with q-q plots were used to ensure dependent variables met the ANOVA's and Pearson Correlation's assumption of normality. Levene's test for equality of variances was used to ensure dependent variables met the ANOVA's assumption of equal variance. Mauchly's test of sphericity was used to ensure the dependent variable met the repeated measures ANOVA's assumption of sphericity. If data did not meet the specified assumptions, it was modified to fit the assumptions by squaring, log transforming, or square root transforming the data (Appendix A).

3.1.6.2 Secondary Outcome Measures

One-way ANOVAs were conducted comparing means between groups on the BTSCS, the TSES, and the mental fatigue visual analog scale. Additional one-way ANOVAs were conducted comparing between group means at each mental fatigue visual analog scale measurement time point. The Shapiro-Wilks test conducted on IMI values showed significant departures from normality which were unable to be reconciled using transformations. Thus, the Welch robust test of equality of means was used to conduct a pairwise comparison of group means in place of the 2 x 2 repeated measures ANOVA. 2 (group) x 2 (time) ANOVAs were used in the statistical analysis of all subscales of the NASA-TLX. Pairwise post-hoc comparisons of group means using a one-way ANOVA were conducted on dependent variables which returned significant or nearing significance effects or interactions including the mental fatigue visual analog scale along with the mental demand and frustration subscales of the NASA-TLX.

3.1.6.5 Correlations

Pearson correlations analyses were used to examine the potential of a speed accuracy trade off associated with mental fatigue. Separate correlation analyses were conducted for both the pre and post intervention time points for both the control and fatigue group using mean elbow velocity as the independent variable and resultant error as the dependent variable. Normality was tested using a Shapiro Wilks test.

3.2 Results

3.2.1 Secondary Outcome Measures

Averaged mental fatigue scores were found to be 72.0% higher in the fatigue group relative to the control group ($F = 34.5$, $p = < 0.001$, $\eta_p^2 = 0.476$) (Table 3.1). One way ANOVAs revealed no significant effects of group on mental fatigue at baseline ($F = 0.024$, $p = 0.878$, $\eta_p^2 = 0.001$); however, significant increases in mental fatigue were observed within the fatigue group when means were compared to the control group at minute 2 during the intervention task ($F = 14.1$, $p = <0.001$, $\eta_p^2 = 0.271$), minute 4 ($F = 39.7$, $p = <0.001$, $\eta_p^2 = 0.511$), minute 6 ($F = 41.8$, $p <0.001$, $\eta_p^2 = 0.524$), minute 8 ($F = 47.3$, $p = <0.001$, $\eta_p^2 = 0.555$), and minute 10 ($F = 41.0$, $p <0.001$, $\eta_p^2 = 0.519$) (Figure 3.6). No significant interaction effects were observed in the BTSCS or the TSES (Table 3.1). Effects approaching significance were observed in the IMI scores between groups during the pre-intervention dart set ($F = 2.66$, $p = 0.113$, $\eta_p^2 = 0.062$) and near significant effects were observed in the IMI scores between groups during the post-intervention dart set ($F = 4.127$, $p = 0.051$, $\eta_p^2 = 0.092$). IMI scores increased by 0.46% from pre- to post-intervention in the control group and decreased by 2.77% from pre- to post-intervention in the fatigue group (Table 3.1). Near significant interaction effects were observed in the Mental Demand subscale of the NASA-TLX ($F = 3.887$, $p = 0.056$, $\eta_p^2 = 0.093$) with significant main effects of time ($F = 21.1$, $p < 0.001$, $\eta_p^2 = 0.357$). Post-hoc two sided paired t-tests of the NASA-TLX mental demand subscale revealed near significant effects of time on the control group $t(19) = -2.06$, $p = 0.053$ with a significant effect of time on the fatigue group $t(19) = -3.88$, $p = 0.001$. The frustration subscale of the NASA-TLX also revealed near significant interaction effects ($F = 3.48$, $p = 0.07$, $\eta_p^2 = 0.084$) with a significant main effect of time ($F = 17.9$, $p < 0.001$, $\eta_p^2 = 0.093$). Post-hoc two sided paired t-tests of the NASA-TLX frustration subscale revealed no significant effects of time on the control group $t(19) = -1.55$, $p = 0.138$ with a significant effect of time on the fatigue group $t(19) = -3.86$, $p = 0.001$. No significant interaction effects were observed in any other subscales of the NASA-TLX (Table 3.2).

Table 3.1: Mean (standard deviation) scores for the NASA-TLX secondary outcome measure with p-values, f-values, and partial eta squared for interaction effects of time and group.

	Control		**Fatigue**				
	Pre	**Post**	**Pre**	**Post**	**P - value**	**F**	**ηp2**
NASA Task Load Index Variables							
Mental Demand	5.35 (4.29)	6.85 (4.60)	5.00 (4.29)	8.80 (4.29)	0.056	3.89	0.093
Physical Demand	4.60 (3.60)	5.20 (4.30)	4.75 (4.07)	4.47 (2.53)	0.612	0.262	0.007
Temporal Demand	4.25 (3.65)	4.45 (3.83)	3.20 (2.93)	3.60 (2.53)	0.76	0.095	0.002
Performance	9.30 (5.01)	9.20 (5.4)	9.75 (4.00)	9.20 (4.80)	0.702	0.148	0.004
Effort	10.8 (4.48)	11.3 (4.80)	10.0 (5.24)	11.5 (4.03)	0.762	0.093	0.002
Frustration	5.80 (4.69)	6.60 (4.77)	5.02 (4.55)	7.35 (4.77)	0.07	3.49	0.084

Table 3.2: Mean (standard deviation) scores for BTSCS, TSES, IMI, and mental fatigue secondary outcome measures with p-values, f-values, and partial eta squared for main effect of group. Asterisk representing significance.

	Control	Fatigue	p-value	F	ηp2
Mental Fatigue	21.5 (12.3)	47.5 (15.6)	< 0.001*	34.5	0.476
Brief Trait Self Control Scale	45.7 (6.69)	44.8 (7.54)	0.676	0.178	0.005
Task Self Efficacy Scale	5.95 (2.14)	5.45 (1.54)	0.203	1.676	0.042
Pre Intrinsic Motivation Inventory	6.58 (0.581)	6.14 (1.06)	0.113	2.66	0.062
Post Intrinsic Motivation Inventory	6.61 (0.605)	5.97 (1.29)	0.051	4.127	0.092

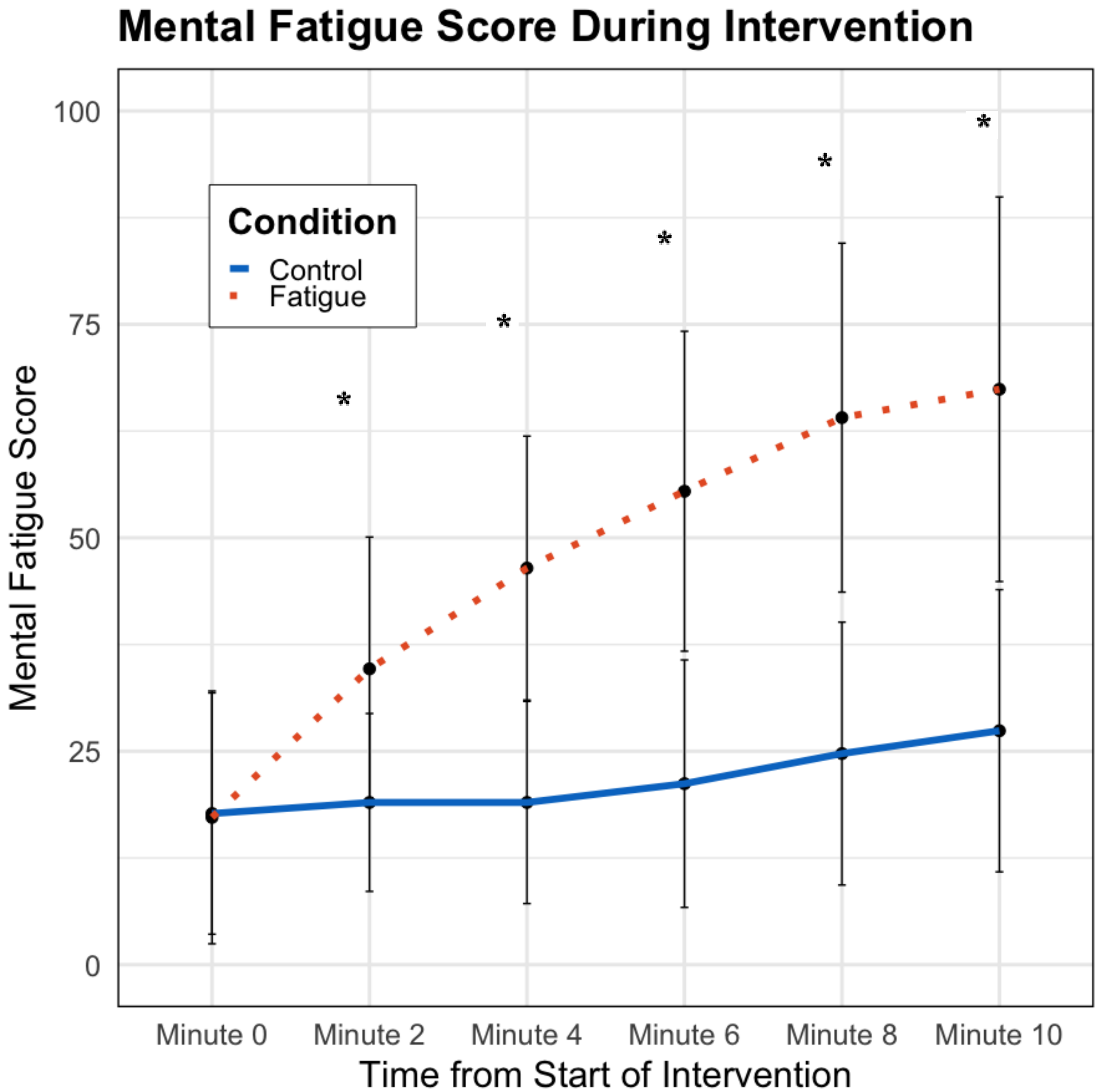

Figure 3.6: Time based changes in group mean mental fatigue score throughout the intervention task for the control group (blue) and the fatigue group (orange). Error bars indicating standard deviation. Asterisk indicating significance.

3.2.2 Accuracy

No significant interaction effects were observed in horizontal ($F = 0.229$, $p = 0.635$, $\eta_p^2 = 0.006$) or vertical ($F = 0.914$, $p = 0.345$, $\eta_p^2 = 0.023$) dart landing position distance (Figure 3.7). Similarly, no significant interaction effects were observed for the resultant error of the dart landing location from the bullseye ($F = 0.011$, $p = 0.918$, $\eta_p^2 = 0.000$) (Figure 3.8).

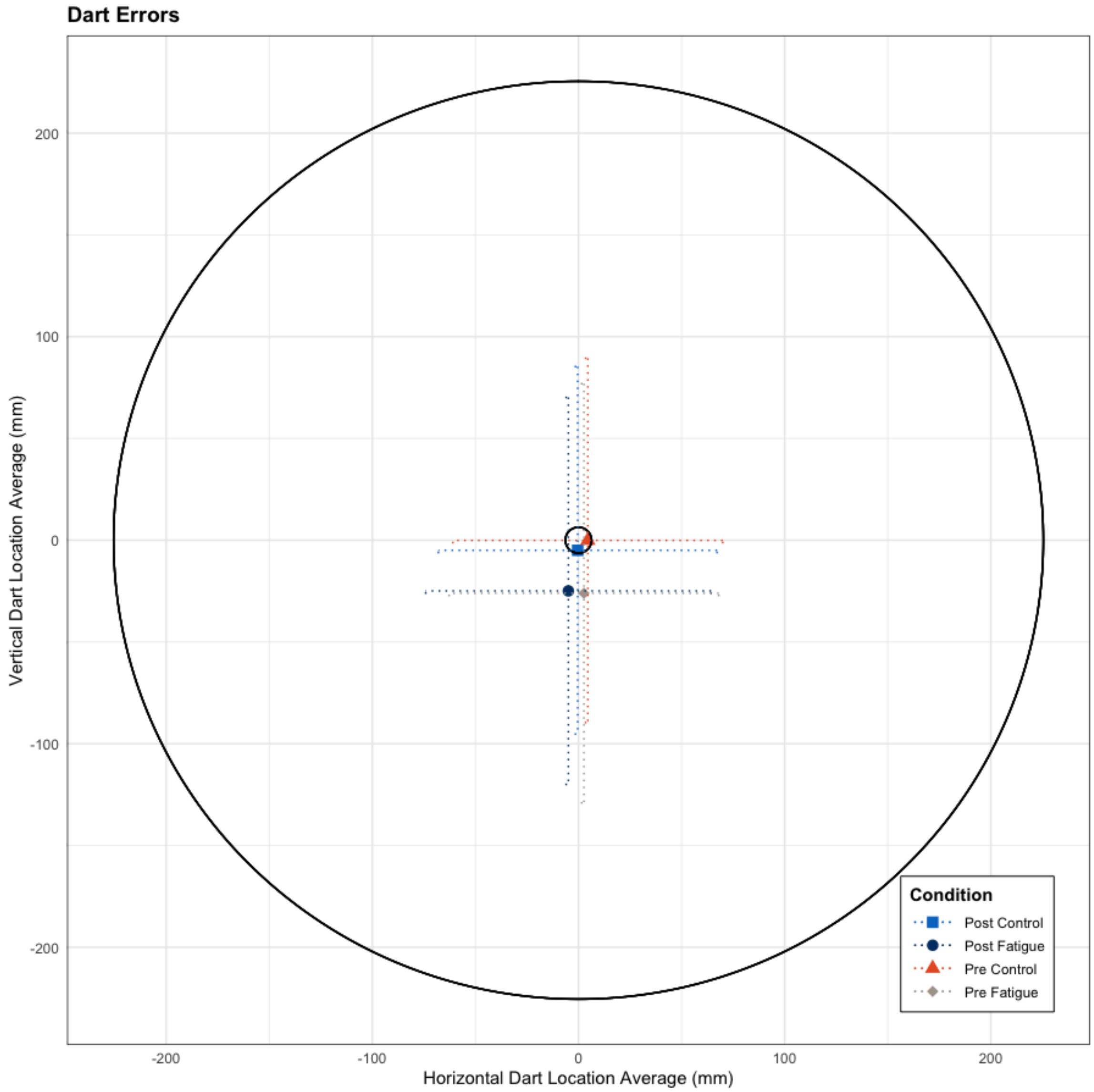

Figure 3.7: Mean dart landing location (mm) for the control group pre-intervention (orange), the control group post intervention (light blue), the fatigue group pre intervention (grey), the fatigue group post intervention (dark blue). Inner black ring indicating the diameter of the bullseye, outer black ring indicating the diameter of the dart board. Error bars indicating standard deviation.

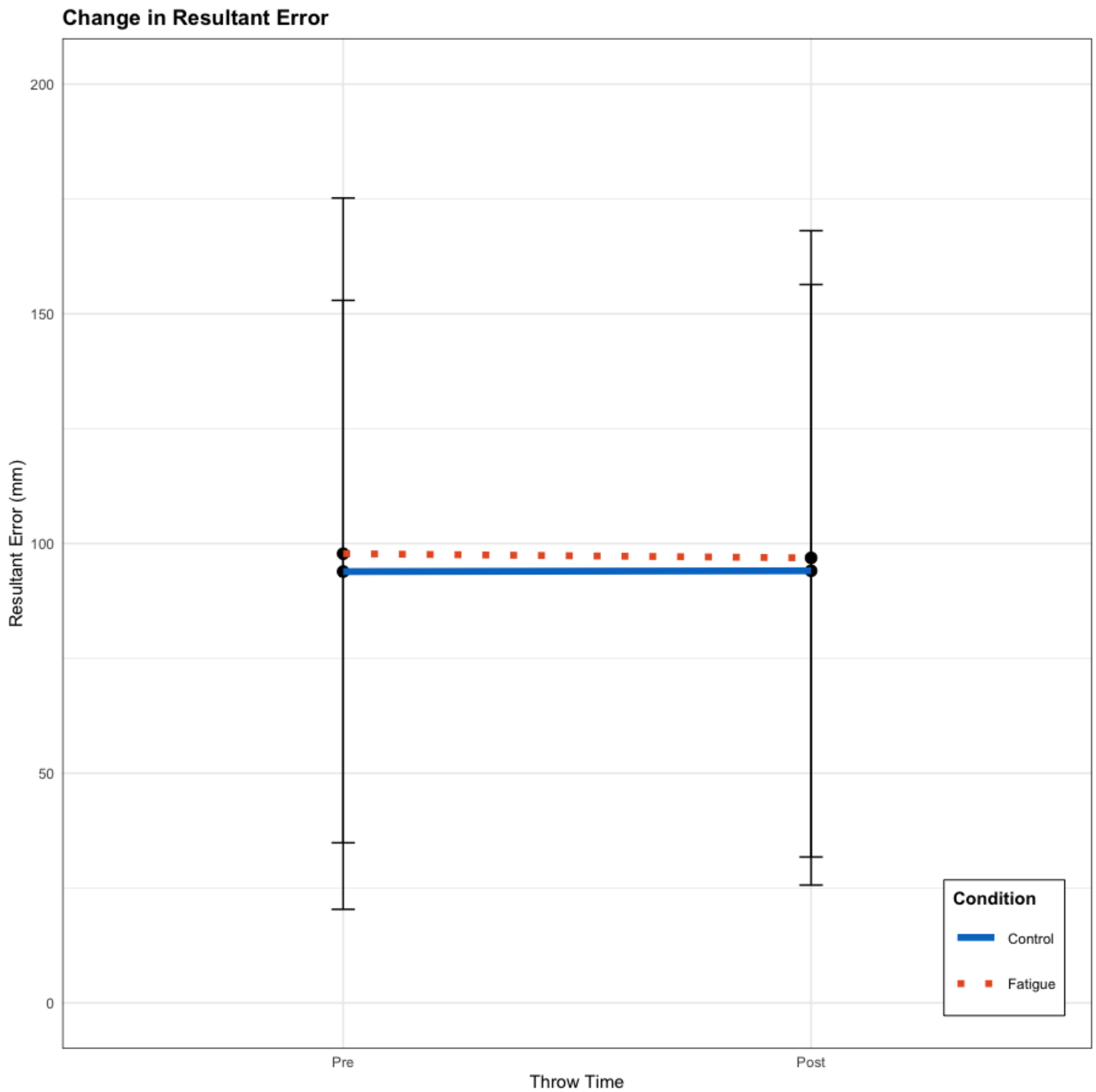

Figure 3.8: Mean resultant error (mm) of dart landing location at bullseye pre and post intervention for the control group (blue) and the fatigue group (orange). Error bars indicating standard deviation.

No significant interaction effect in recalibration rate was observed ($F = 1.341$, $p = 0.254$, $\eta_p^2 = 0.034$) with a non-significant main effect of time ($F = 0.012$, $p = 0.912$, $\eta_p^2 = 0.000$). Recalibration rate decreased by 21.8 mm within the control group from pre-intervention to post intervention and increased by 17.9 mm within the fatigue group during the same time period (Figure 3.9).

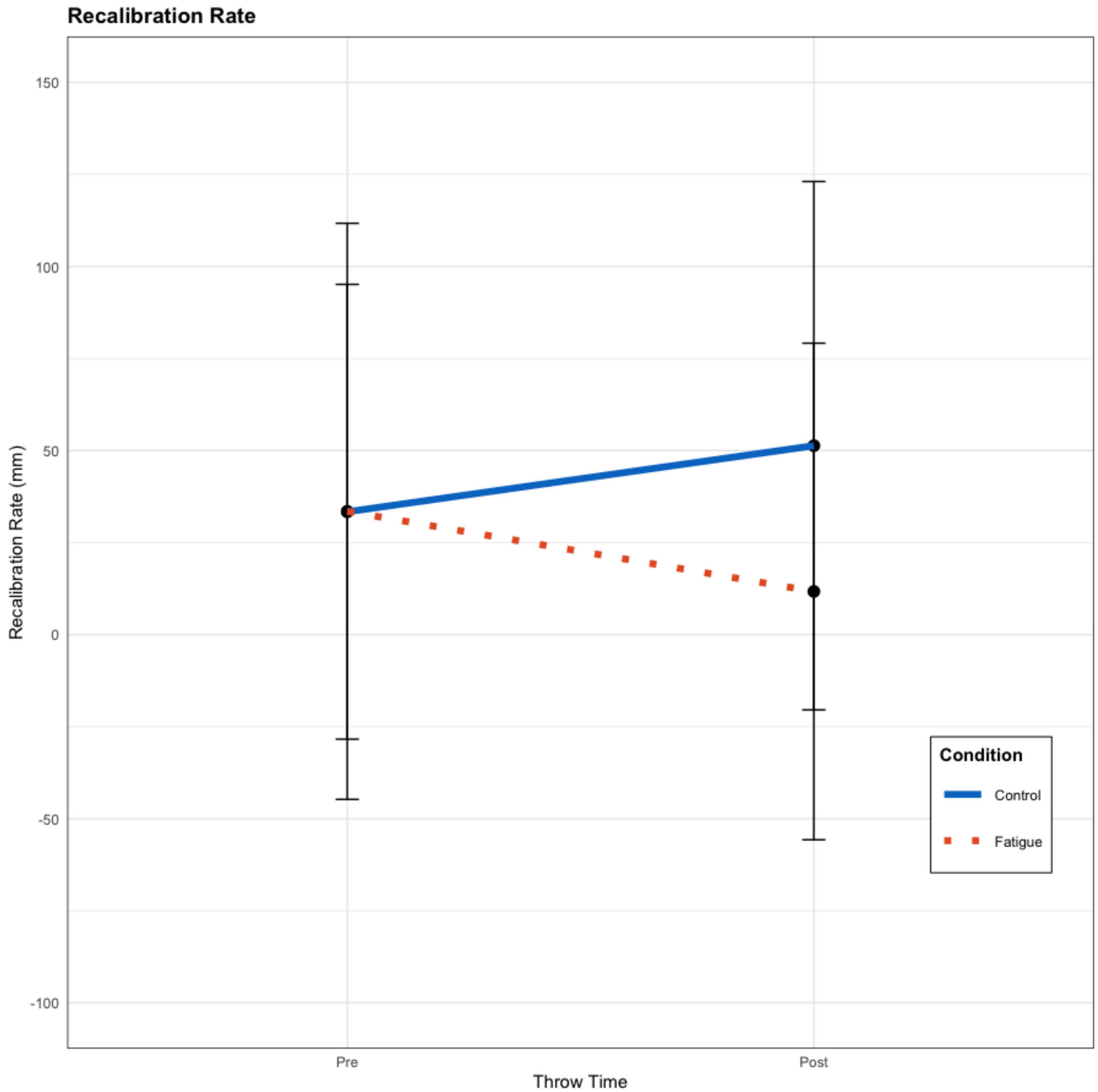

Figure 3.9: Mean recalibration rate (mm) at pre and post intervention for the control group (blue) and the fatigue group (orange). Error bars indicating standard deviation.

3.2.3 Joint Angles

3.2.3.1 - Shoulder

No significant interaction effects were observed in retraction angle ($F = 0.833$, $p = 0.367$, $\eta_p^2 = 0.021$) (Figure 3.10) and end of movement angle ($F = 0.179$, $p = 0.675$, $\eta_p^2 = 0.005$) (Figure 3.11) in the horizontal adduction/abduction direction about the shoulder joint, nor for retraction angle in the angle of elevation direction ($F = 0.06$, $p = 0.807$, $\eta_p^2 = 0.002$)

(Figure 3.12). However, a significant interaction effect with a large effect size was found for angle of elevation end of movement angle ($F = 6.795$, $p = 0.013$, $\eta_p^2 = 0.152$) with no significant main effect of time ($F = 1.61$, $p = 0.213$, $\eta_p^2 = 0.041$). End of movement angle in the flexion/extension direction decreased by 2.2° from pre to post intervention in the mental fatigue group, compared to a 0.8° increase in the control group. Post hoc paired t-tests found no significant differences from pre to post intervention among the control group $t(19) = -1.149$, $p = 0.265$ with significant differences from pre to post intervention among the fatigue group $t(19) = 2.384$, $p = 0.028$ (Figure 3.13).

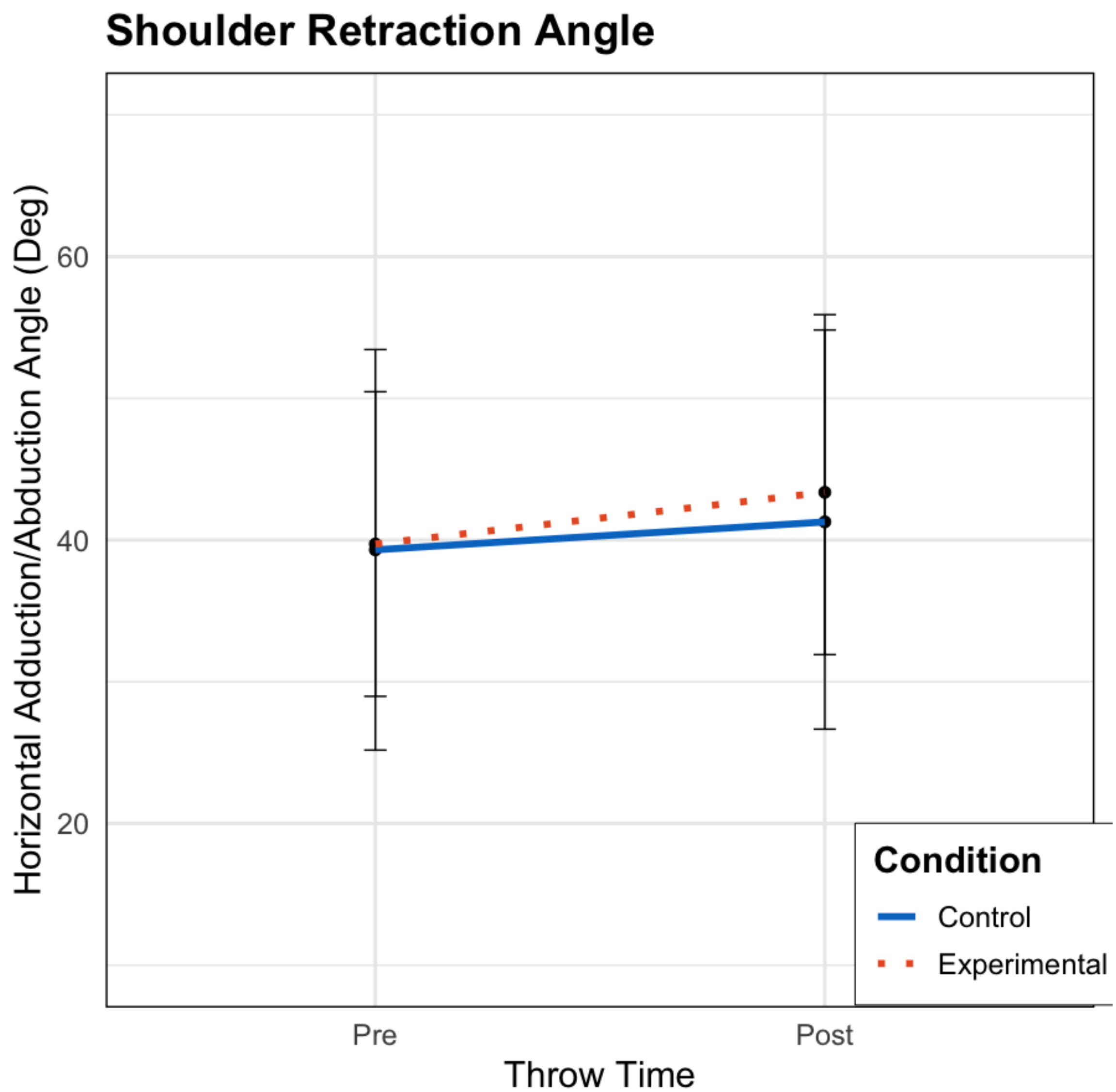

Figure 3.10: Mean shoulder retraction angle relative to anatomical position in the horizontal adduction/abduction direction for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

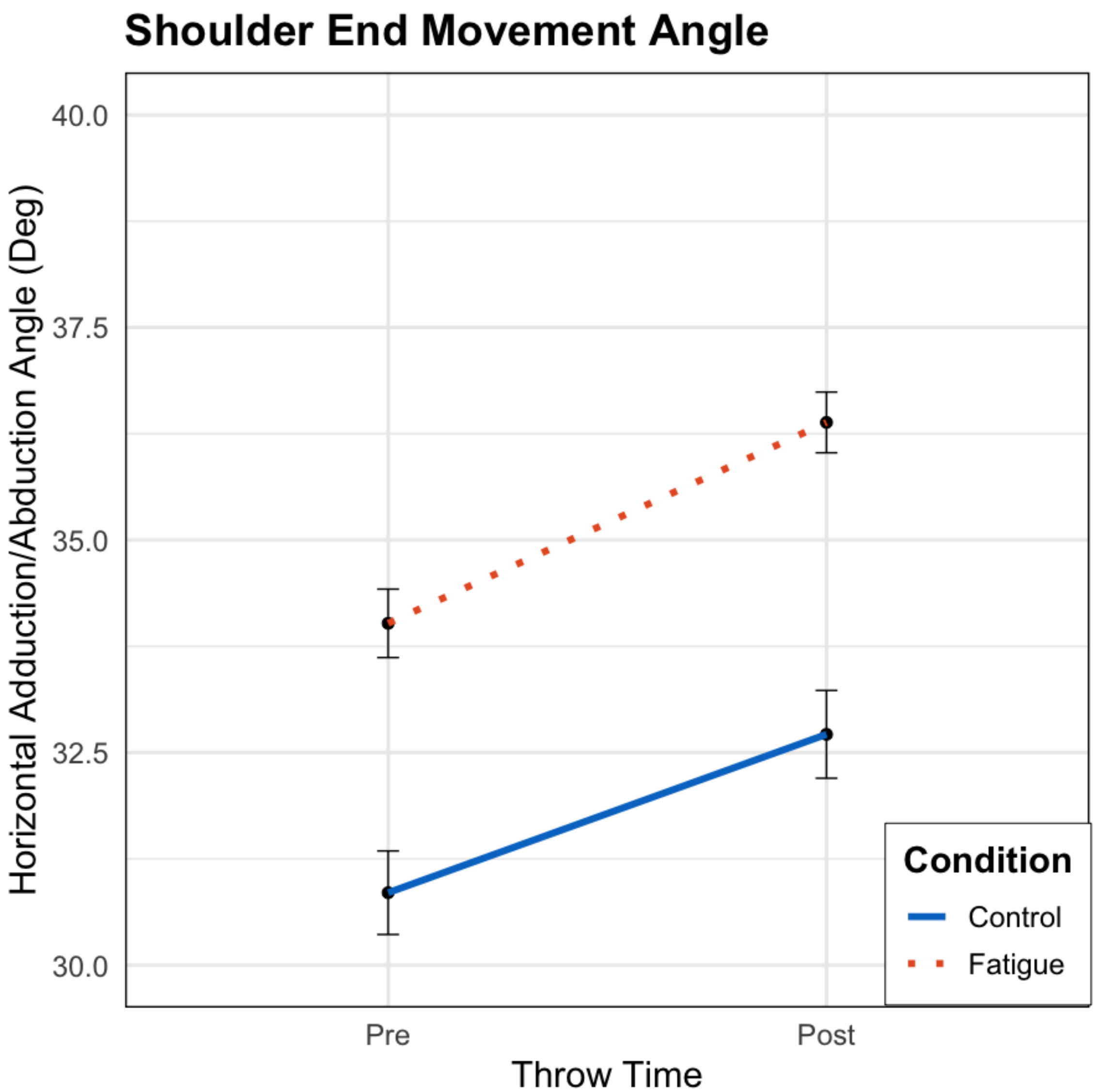

Figure 3.11: Mean shoulder end of movement angle relative to anatomical position in the horizontal adduction/abduction direction for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

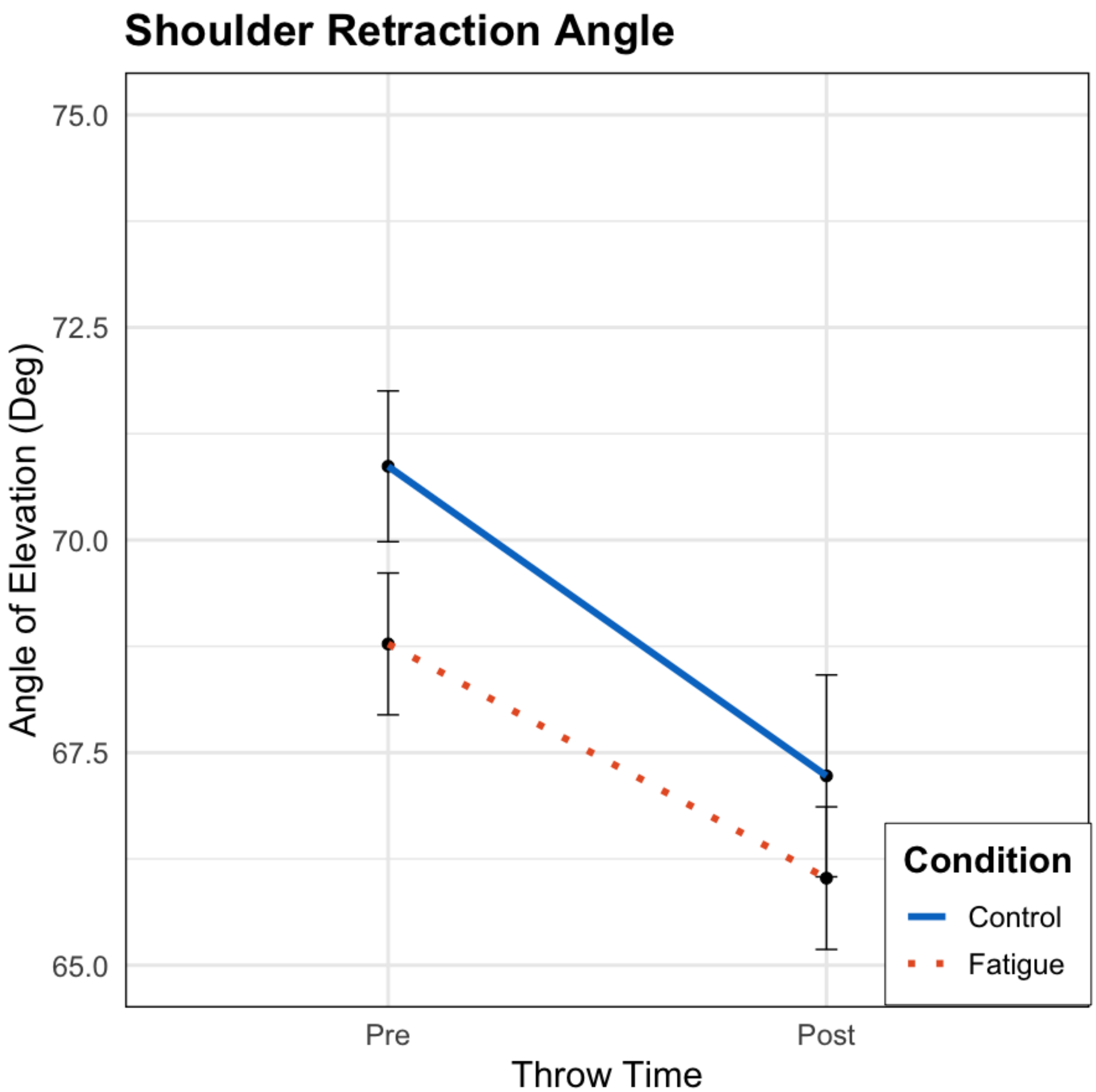

Figure 3.12: Mean shoulder retraction angle relative to anatomical position in the angle of elevation direction for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

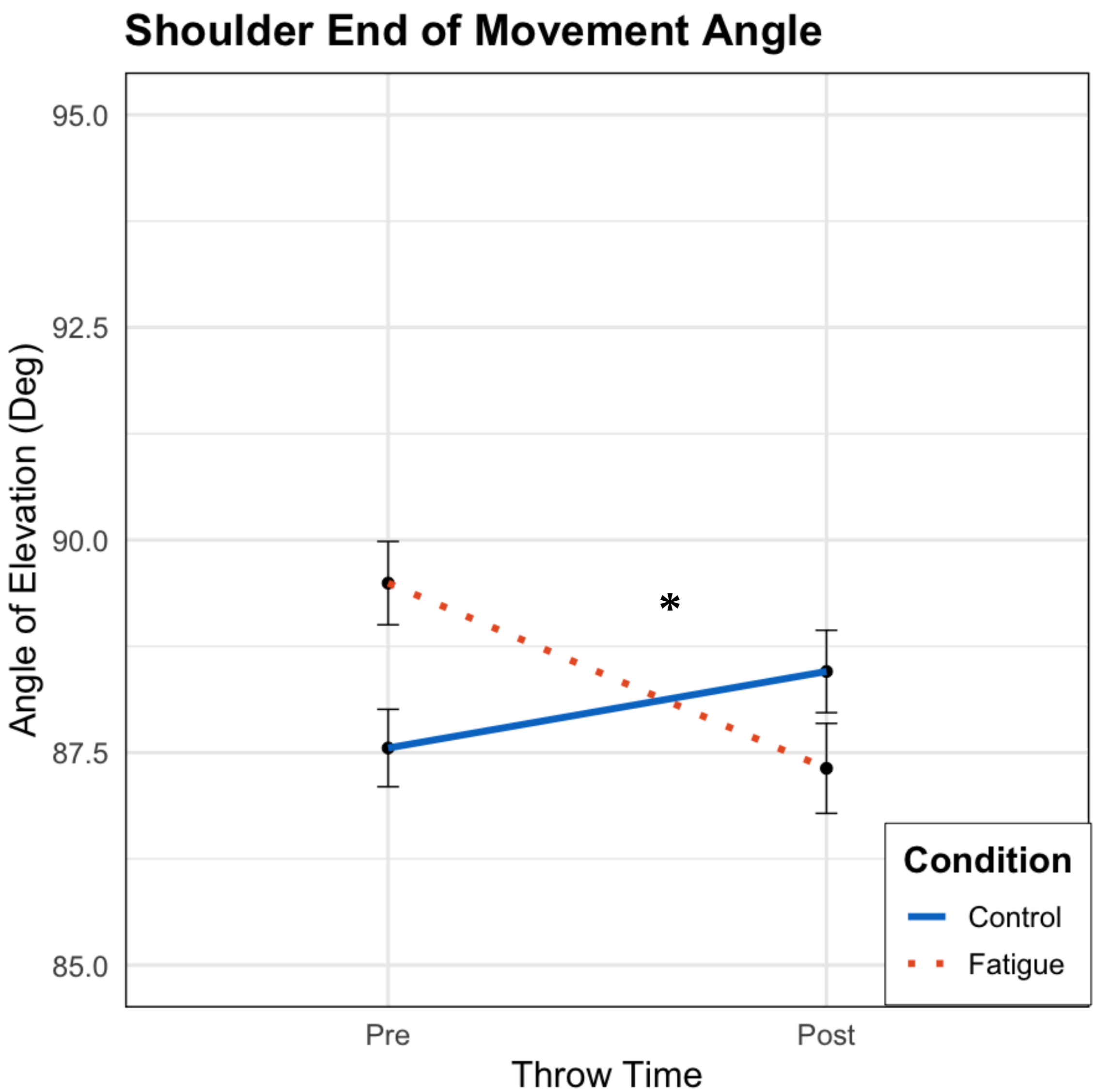

Figure 3.13: Mean shoulder end of movement angle relative to anatomical position in the angle of elevation direction for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

3.2.3.2 – Elbow

No significant interaction effects were observed in retraction angle ($F = 2.67$, $p = 0.111$, $\eta_p^2 = 0.066$) (Figure 3.14) and end of movement angle ($F = 0.022$, $p = 0.882$, $\eta_p^2 = 0.001$) in the flexion/extension direction about the elbow joint (Figure 3.15).

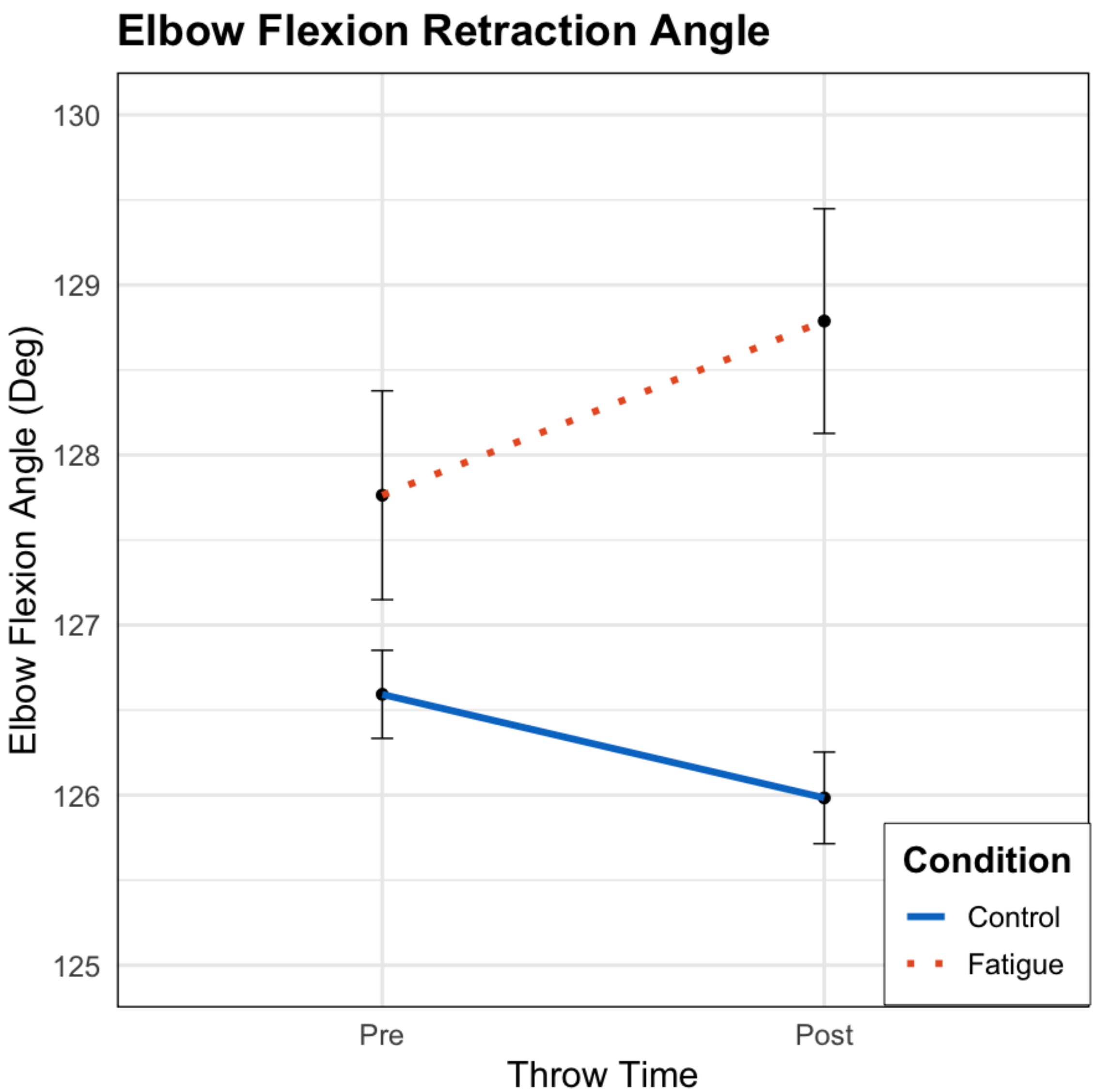

Figure 3.14: Mean retraction elbow angle relative to anatomical position in the flexion/extension directions for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

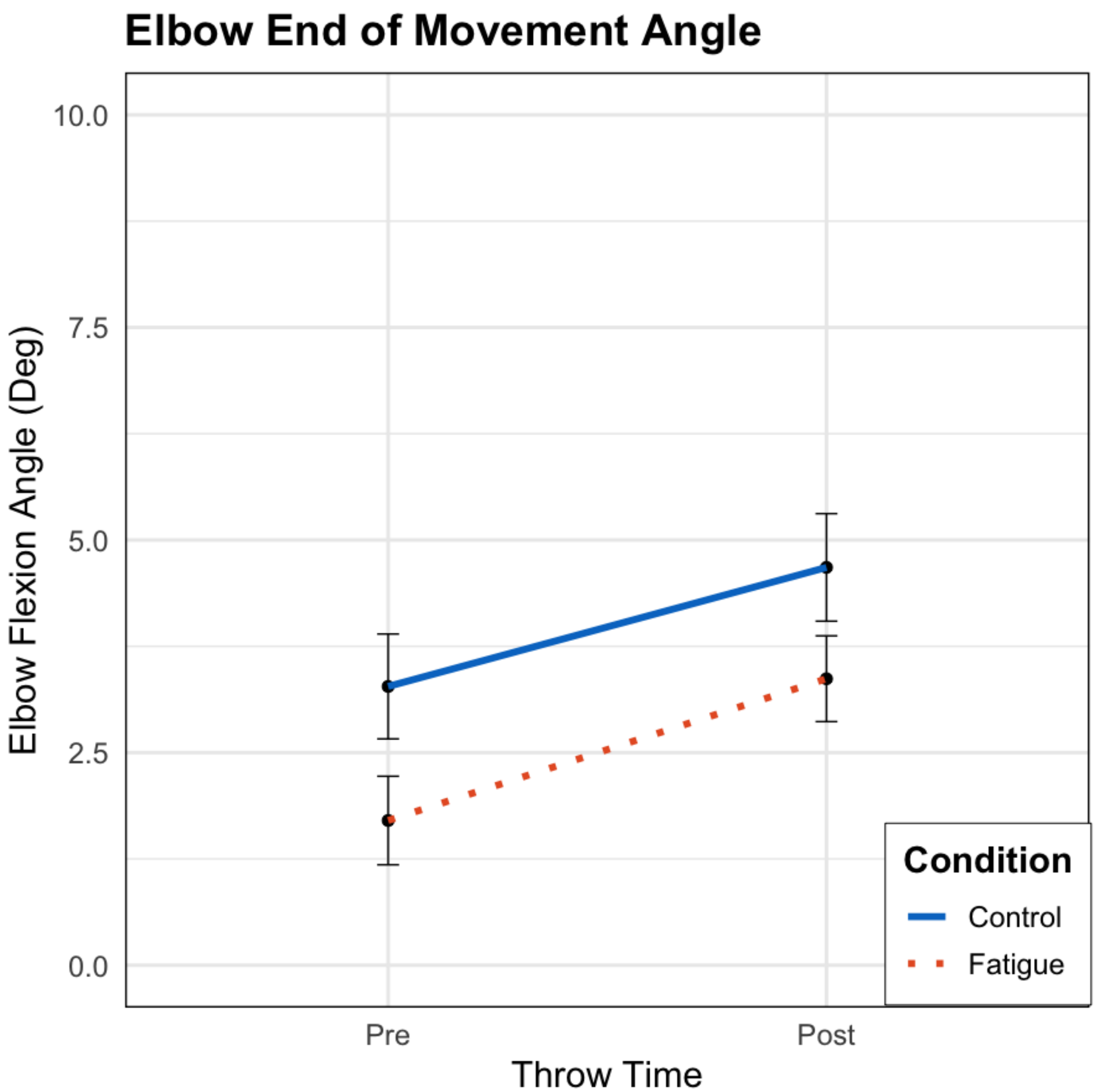

Figure 3.15: Mean end of movement elbow angle relative to anatomical position in the flexion/extension directions for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

3.2.3.3 – Wrist

No significant interaction effects were observed in retraction angle ($F = 1.31$, $p = 0.260$, $\eta_p^2 = 0.033$) (Figure 3.16) and end of movement angle ($F = 0.080$, $p = 0.779$, $\eta_p^2 = 0.002$) (Figure 3.17) in the ulnar/radial deviation directions of the wrist. No significant interaction effects were observed in retraction angle ($F = 0.256$, $p = 0.616$, $\eta_p^2 = 0.007$)

(Figure 3.18) and end of movement angle ($F = 1.33$, $p = 0.257$, $\eta_p^2 = 0.034$) (Figure 3.19) in the flexion/extension directions of the wrist.

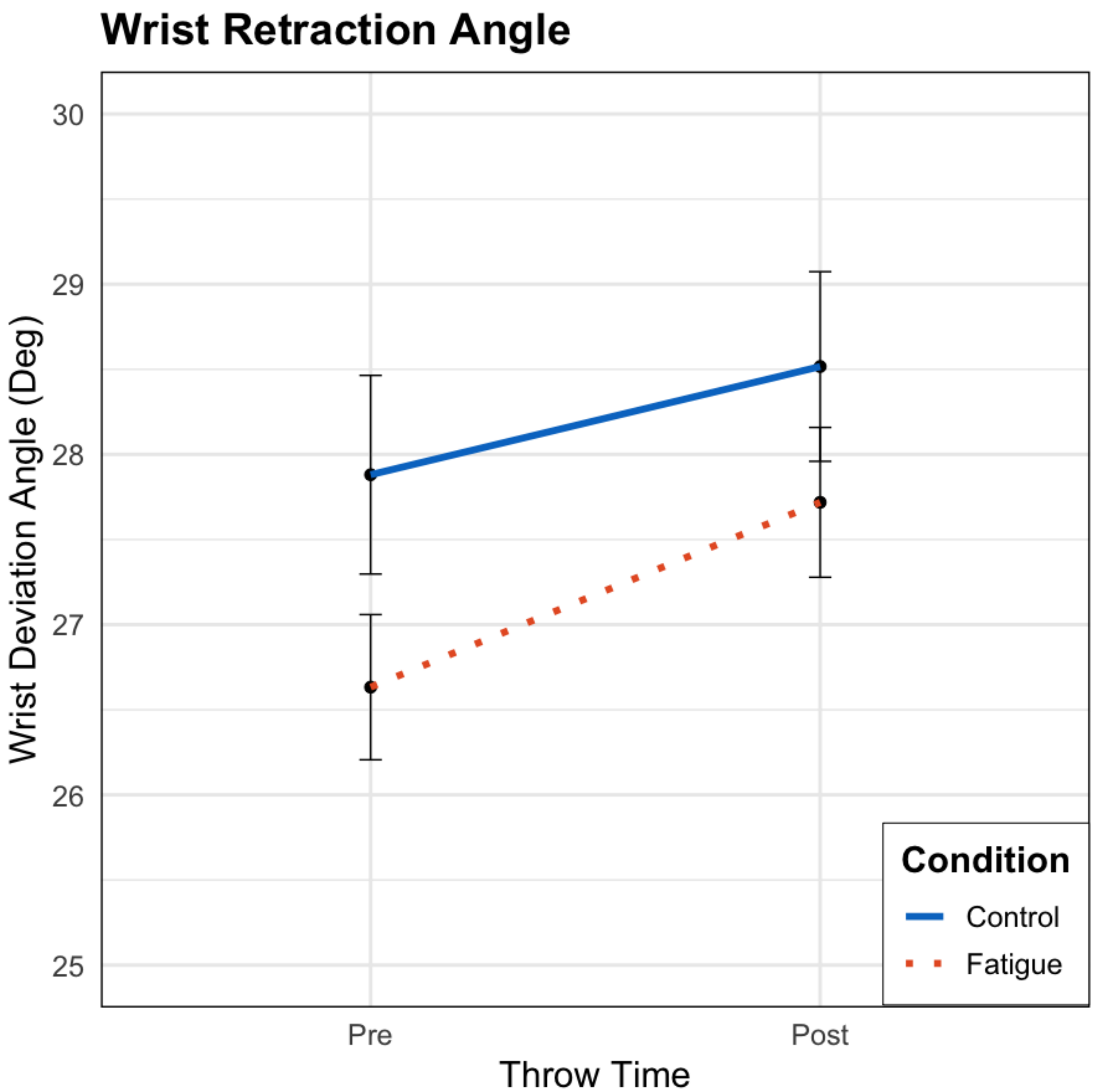

Figure 3.16: Mean wrist retraction angle relative to anatomical position in the ulnar/radial deviation direction for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

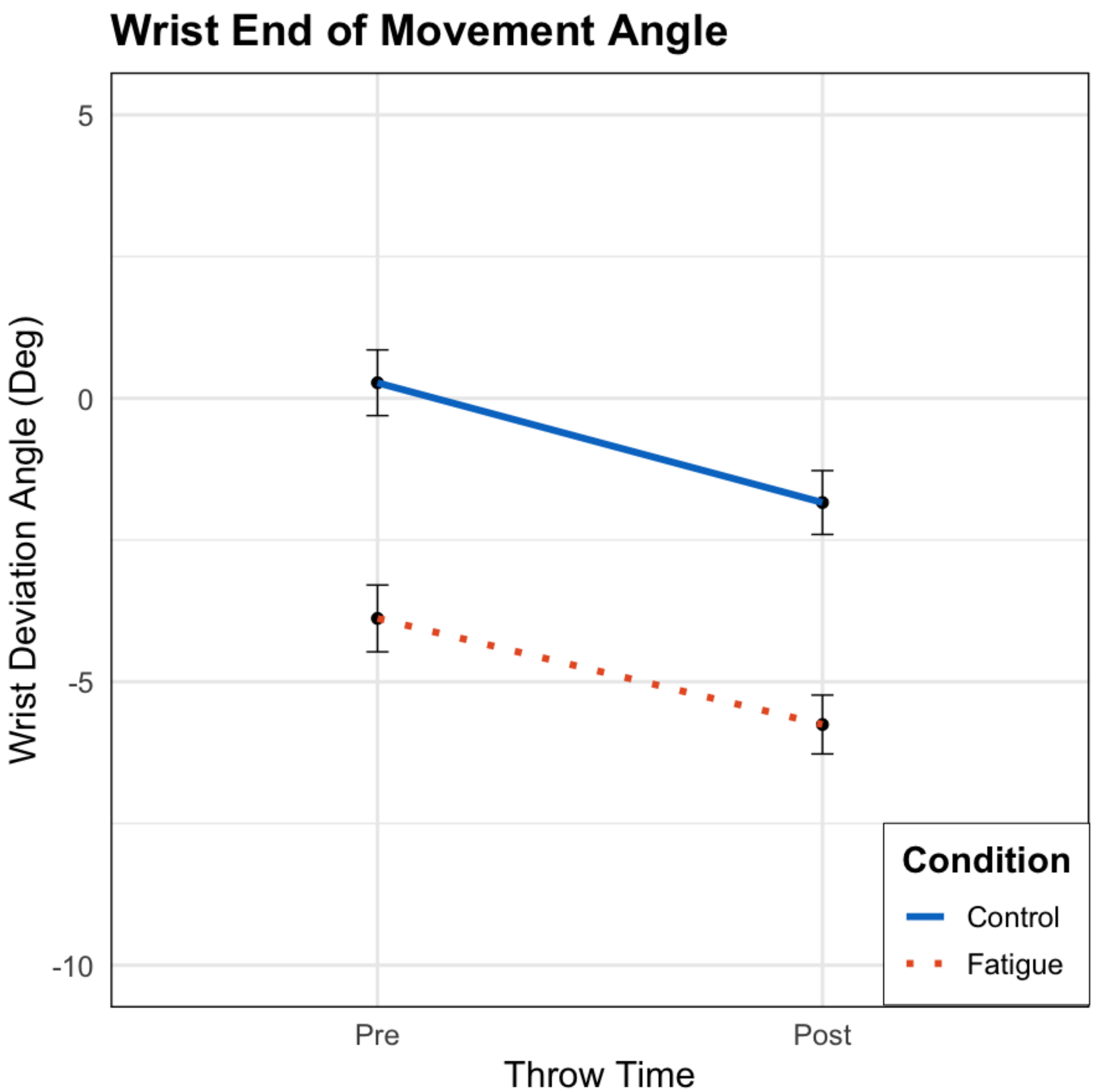

Figure 3.17: Mean wrist end of movement angle relative to anatomical position in the ulnar/radial deviation direction for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

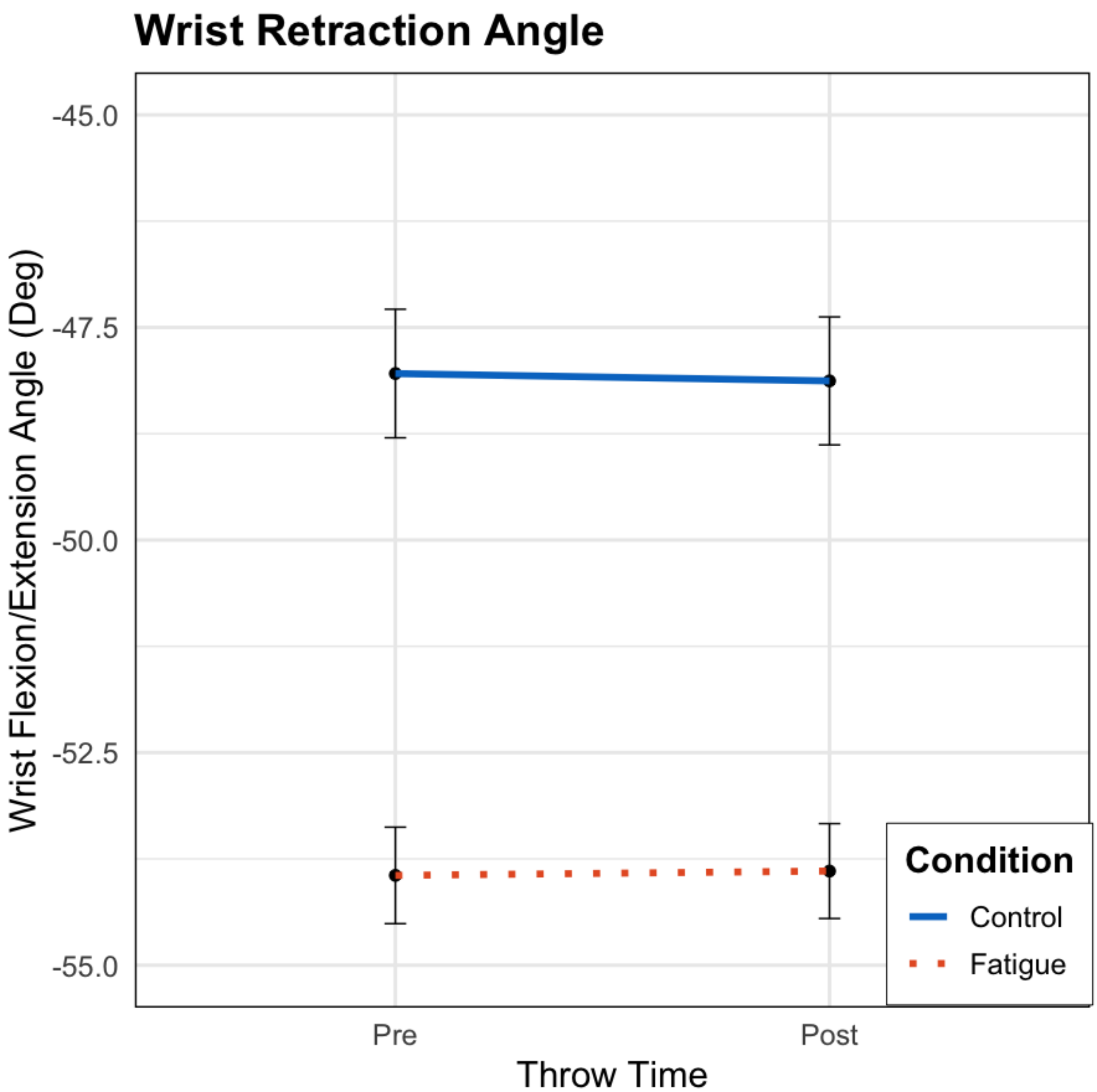

Figure 3.18: Mean wrist retraction angle relative to anatomical position in the flexion/extension direction for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

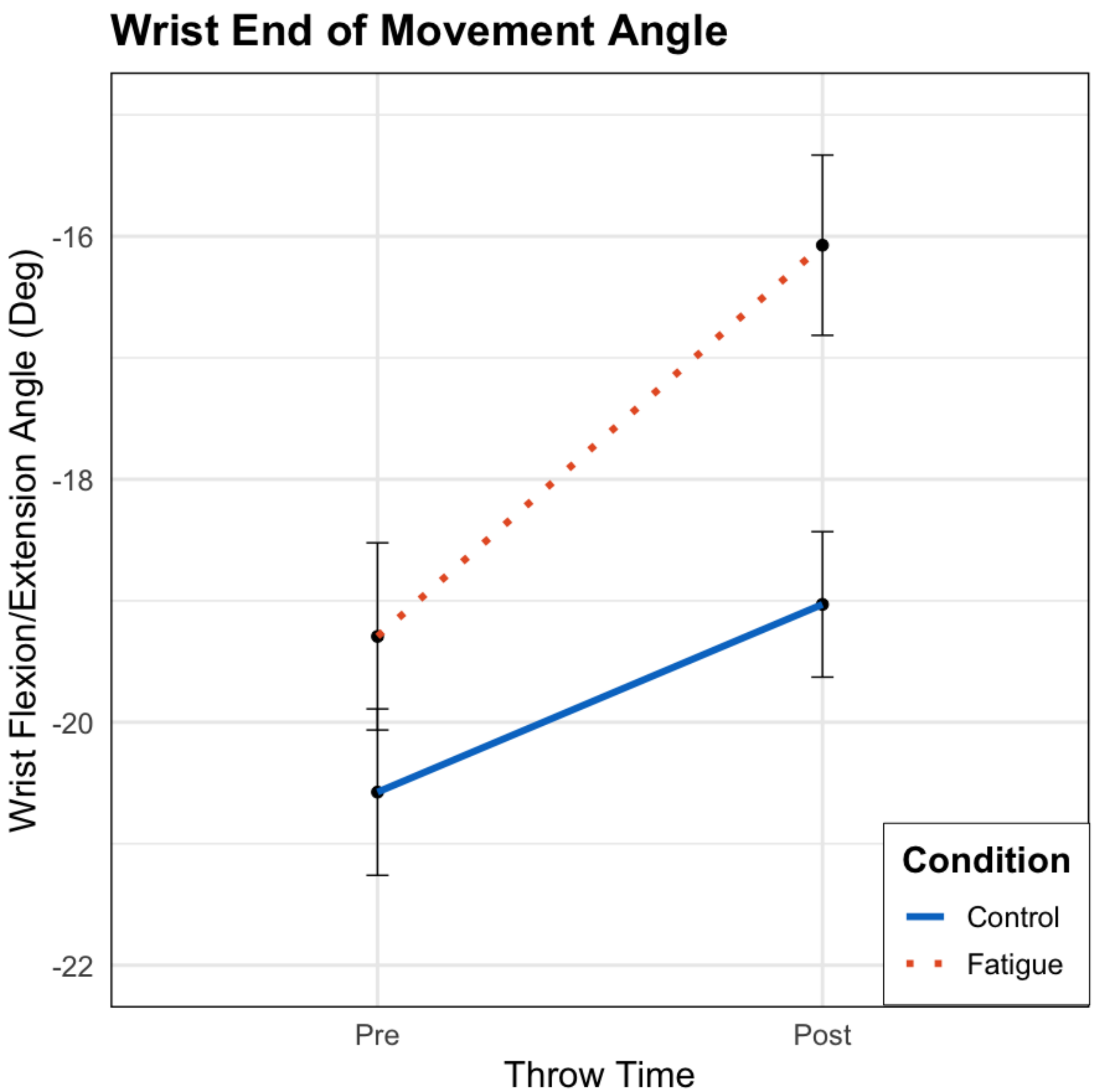

Figure 3.19: Mean wrist end of movement angle relative to anatomical position in the flexion/extension direction for the control group (blue) and the fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

3.2.4 Joint Velocities

No significant interaction effects were observed in shoulder velocity in the horizontal adduction/abduction ($F = 1.02$, $p = 0.318$, $\eta_p^2 = 0.026$) (Figure 3.20) and angle of elevation ($F = 1.28$, $p = 0.264$, $\eta_p^2 = 0.033$) (Figure 3.21) directions, elbow velocity in the flexion/extension direction ($F = 0.066$, $p = 0.799$, $\eta_p^2 = 0.002$) (Figure 3.22) and wrist velocity in the flexion/extension directions ($F = 0.607$, $p = 0.441$, $\eta_p^2 = 0.016$) (Figure 3.23) and in the ulnar/radial deviation ($F = 0.536$, $p = 0.469$, $\eta_p^2 = 0.014$) (Figure 2.24).

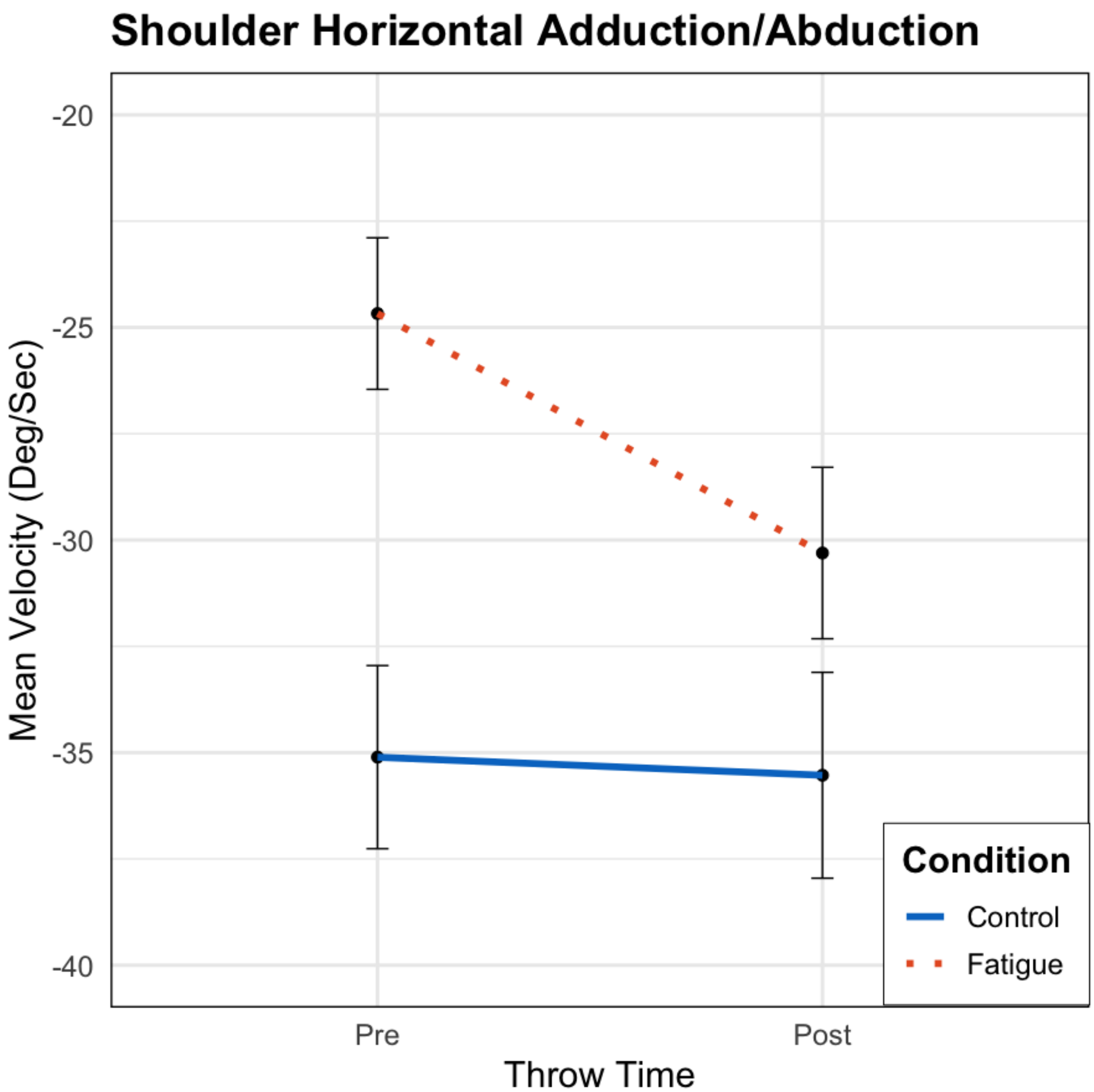

Figure 3.20: Mean velocity (degrees/seconds) of the shoulder in the horizontal adduction/abduction direction for the control group (blue) and fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

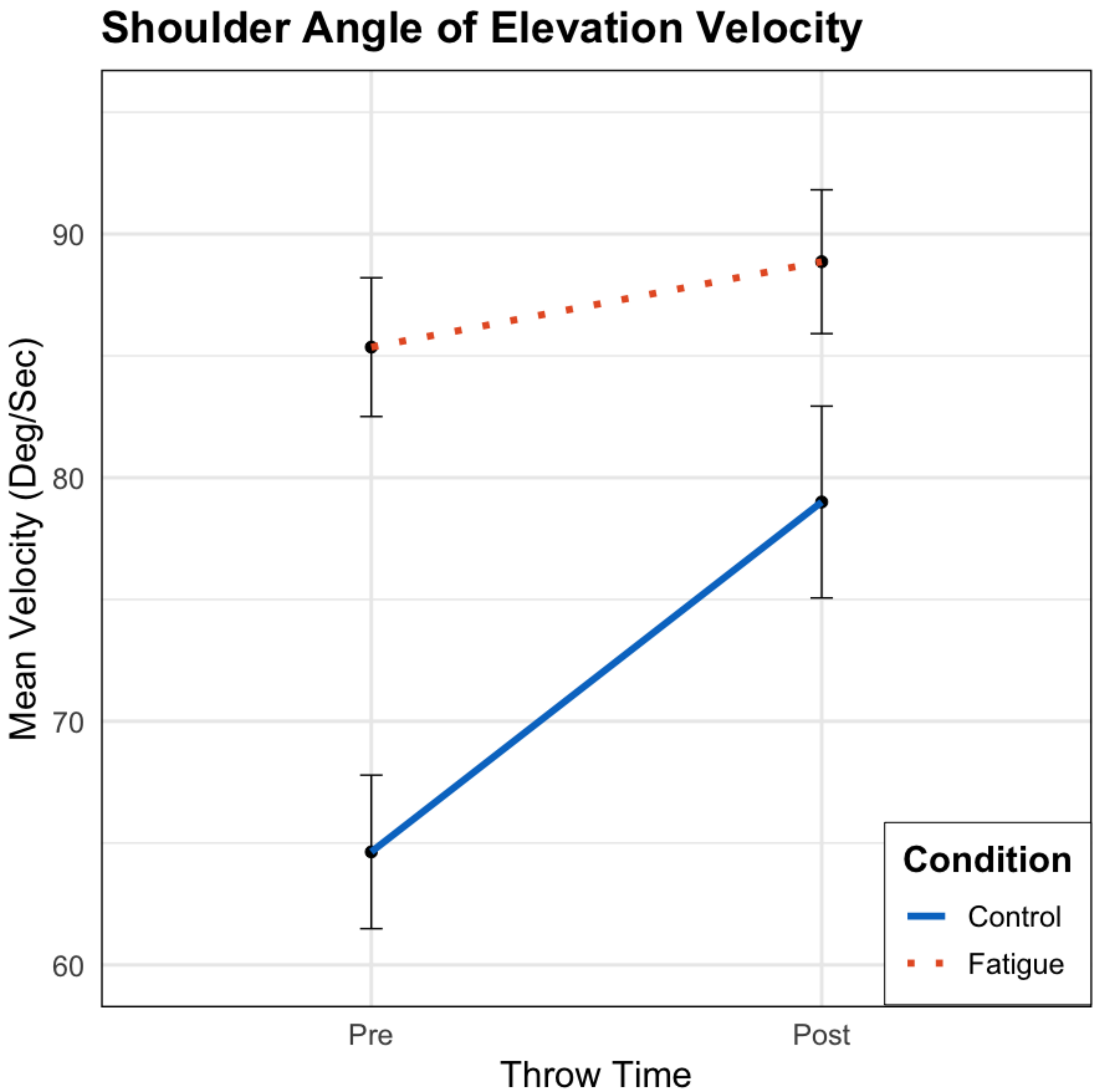

Figure 3.21: Mean velocity (degrees/seconds) of the shoulder in the angle of elevation direction for the control group (blue) and fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

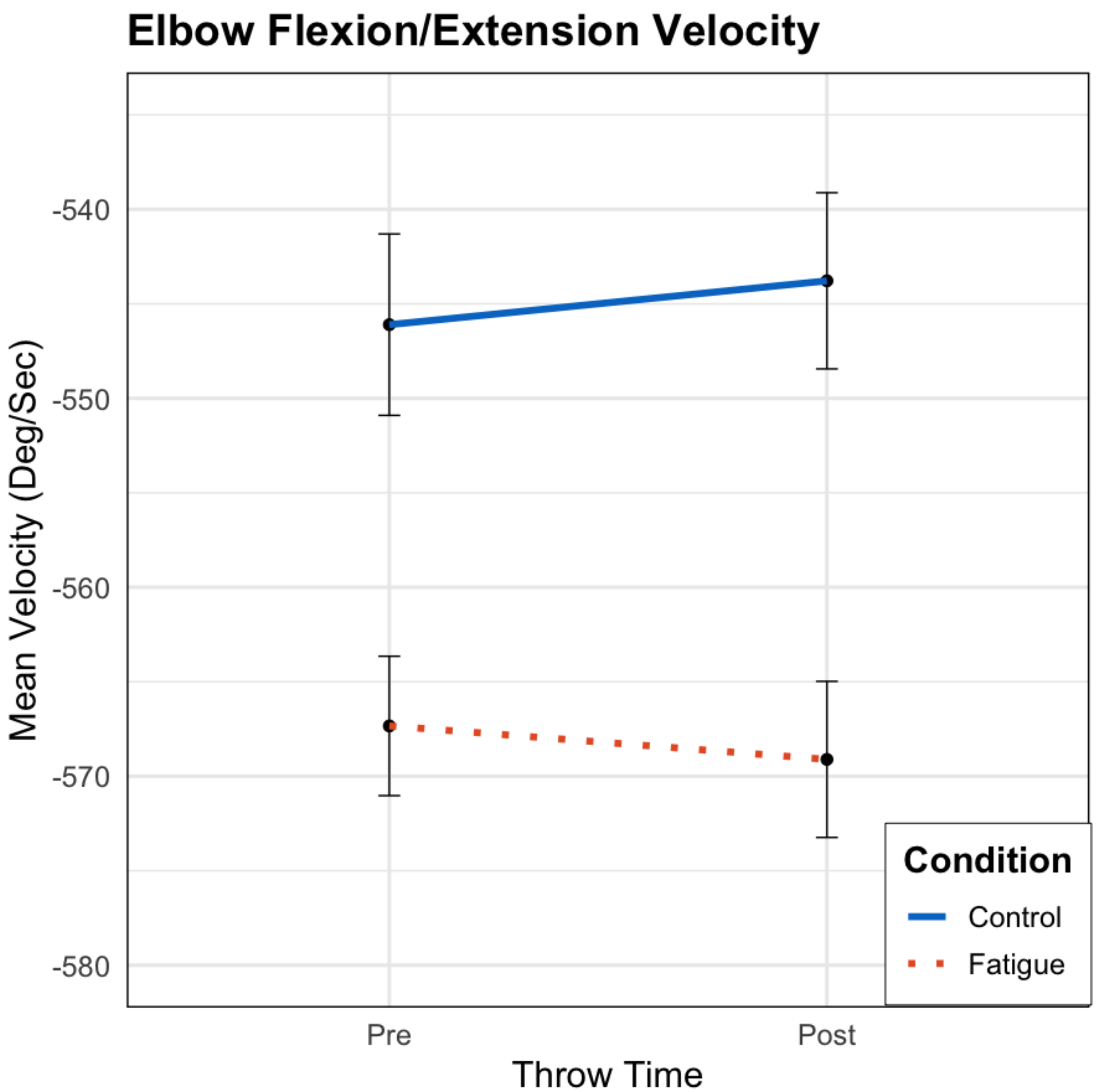

Figure 3.22: Mean velocity (degrees/seconds) of the elbow in the flexion/extension direction for the control group (blue) and fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

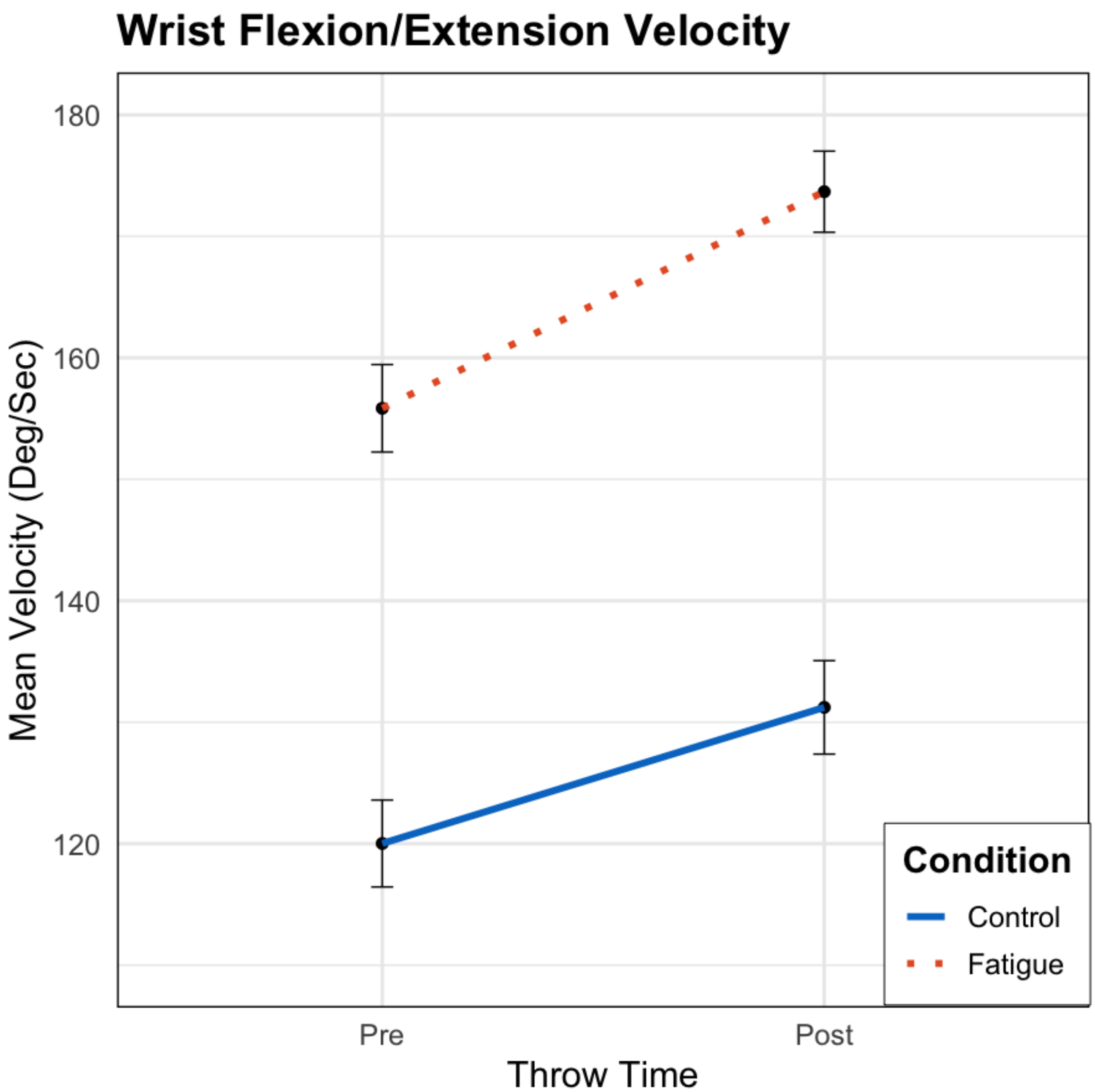

Figure 3.23: Mean velocity (degrees/seconds) of the wrist in the flexion/extension direction for the control group (blue) and fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

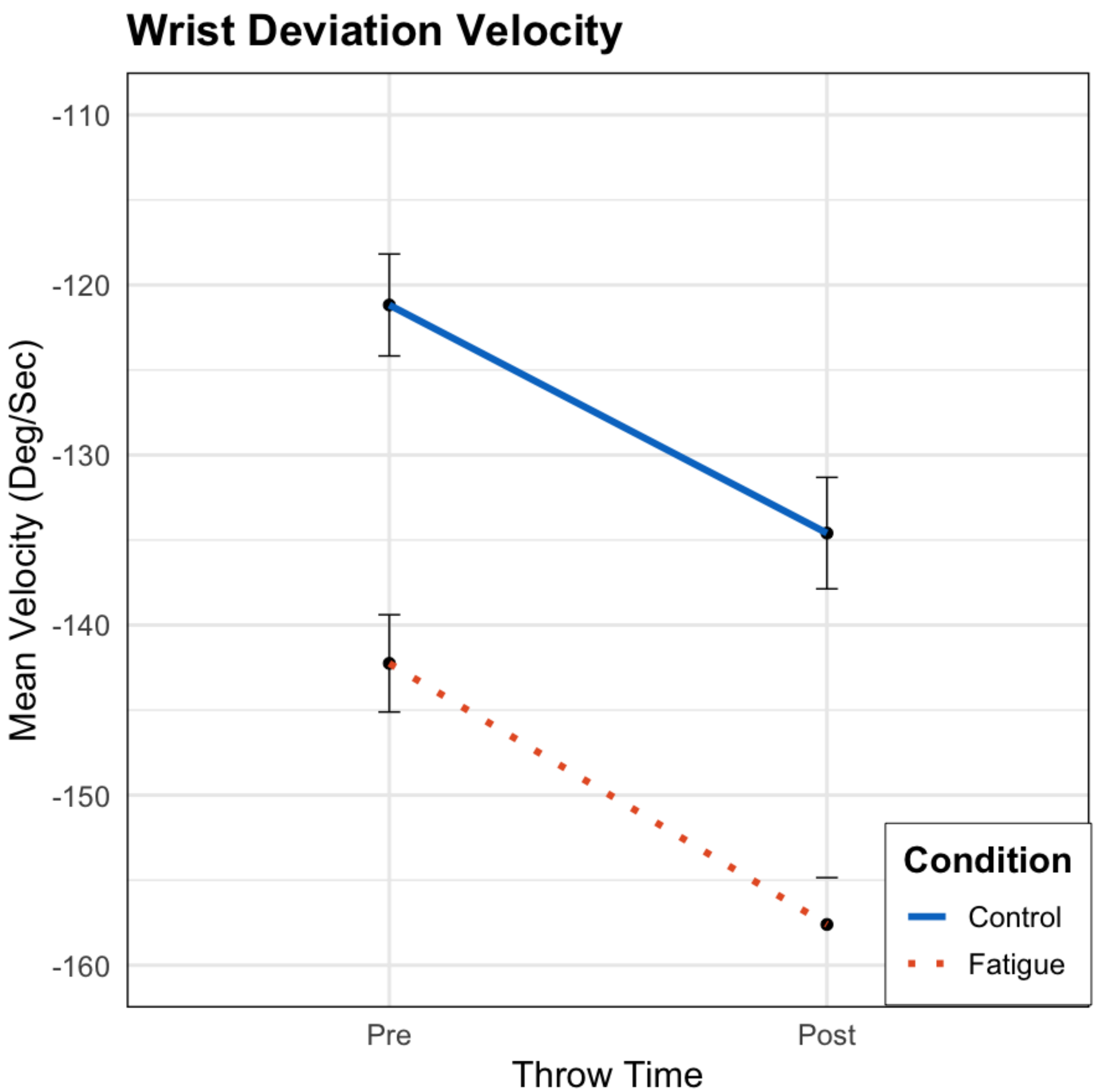

Figure 3.24: Mean velocity (degrees/seconds) of the wrist in the ulnar/radial deviation for the control group (blue) and fatigue group (orange) pre and post intervention. Error bars indicating standard deviation.

3.2.5 Throw and Preparation Time

No significant interaction effects were observed in throw time ($F = 0.033$, $p = 0.857$, $\eta_p^2 = 0.001$) (Figure 3.25). Prep-time revealed an interaction effect approaching significance ($F = 2.09$, $p = 0.156$, $\eta_p^2 = 0.052$) (Figure 3.26) with a significant main effect of time ($F = 14.3$, $p < 0.001$, $\eta_p^2 = 0.273$) with average prep-time in the control group decreasing by 0.12 seconds from pre to post-intervention and decreasing by 0.27 seconds within the fatigue group during the same time period. However, post-hoc analyses revealed no significant effects of group in prep-time in the pre-intervention time period ($F = 0.001$, $p = 0.980$, $\eta_p^2 = 0.000$) nor in the post-intervention time period ($F = 0.361$, $p = 0.551$, $\eta_p^2 = 0.009$).

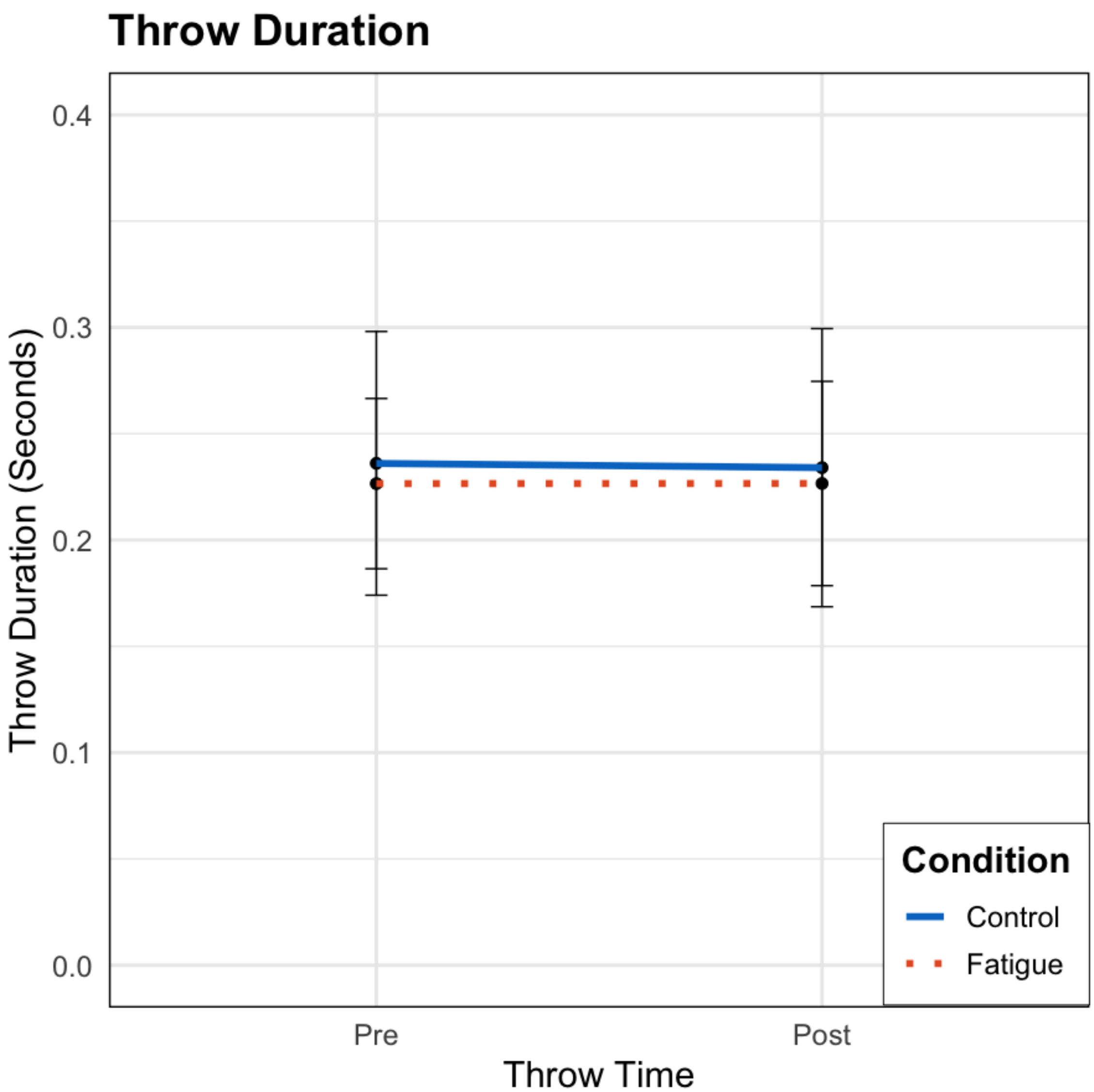

Figure 3.25: Mean of throw duration in seconds pre and post intervention. Error bars indicating standard deviation.

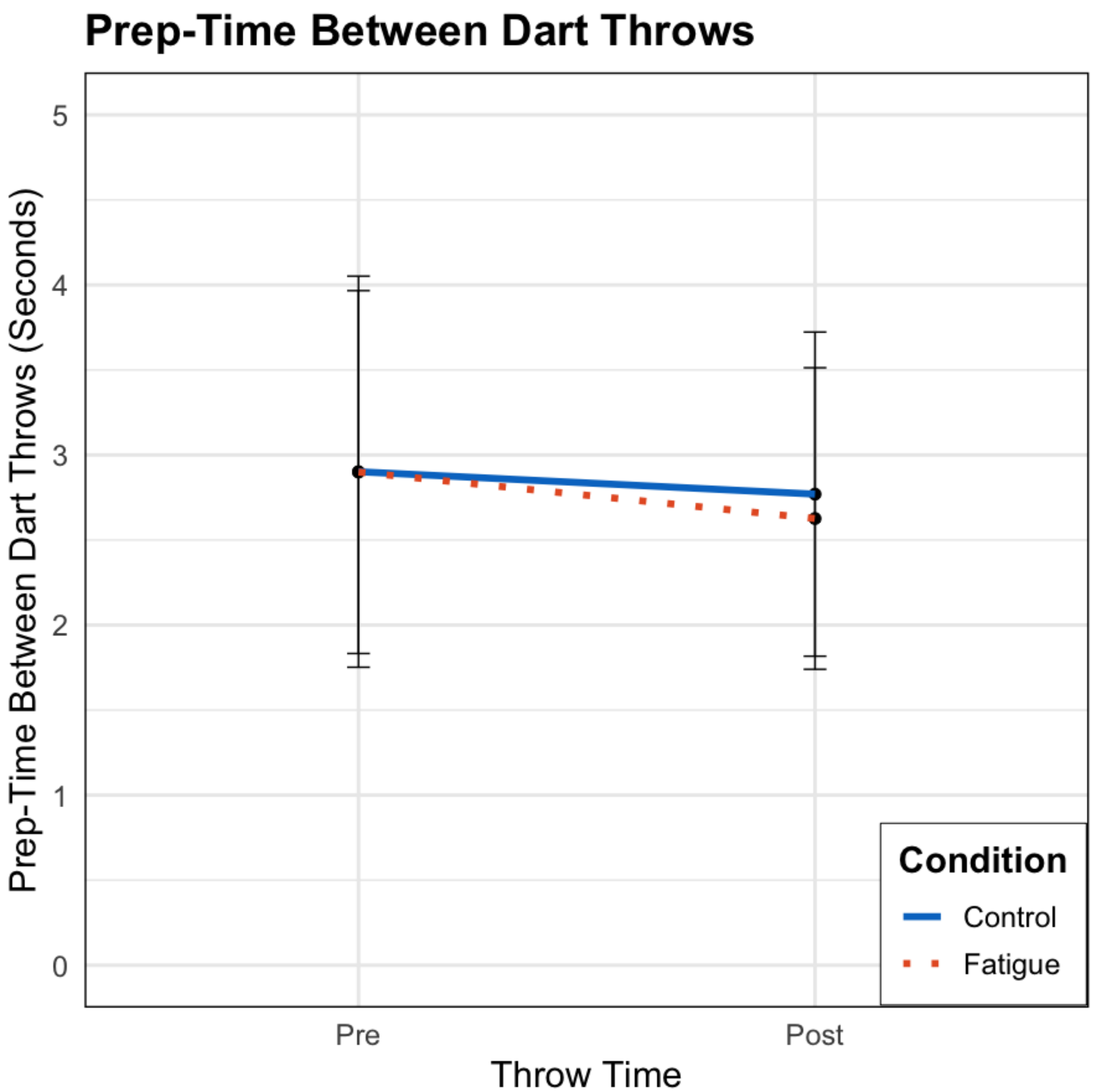

Figure 3.26: Mean of prep-time between dart throws in seconds pre and post intervention. Error bars indicating standard deviation.

3.2.6. Correlations

No significant relationships were found between pre-intervention mean elbow velocity and pre-intervention resultant error among the control group ($p = 0.261$, $r = 0.264$) (Figure 3.27) nor the fatigue group ($p = 0.421$, $r = 0.191$) (Figure 3.28). Similarly, no significant relationships were found between post-intervention mean elbow velocity and post-intervention resultant error among the control group ($p = 0.331$, $r = 0.229$) (Figure 29) nor the fatigue group ($p = 0.339$, $r = -0.225$) (Figure 30).

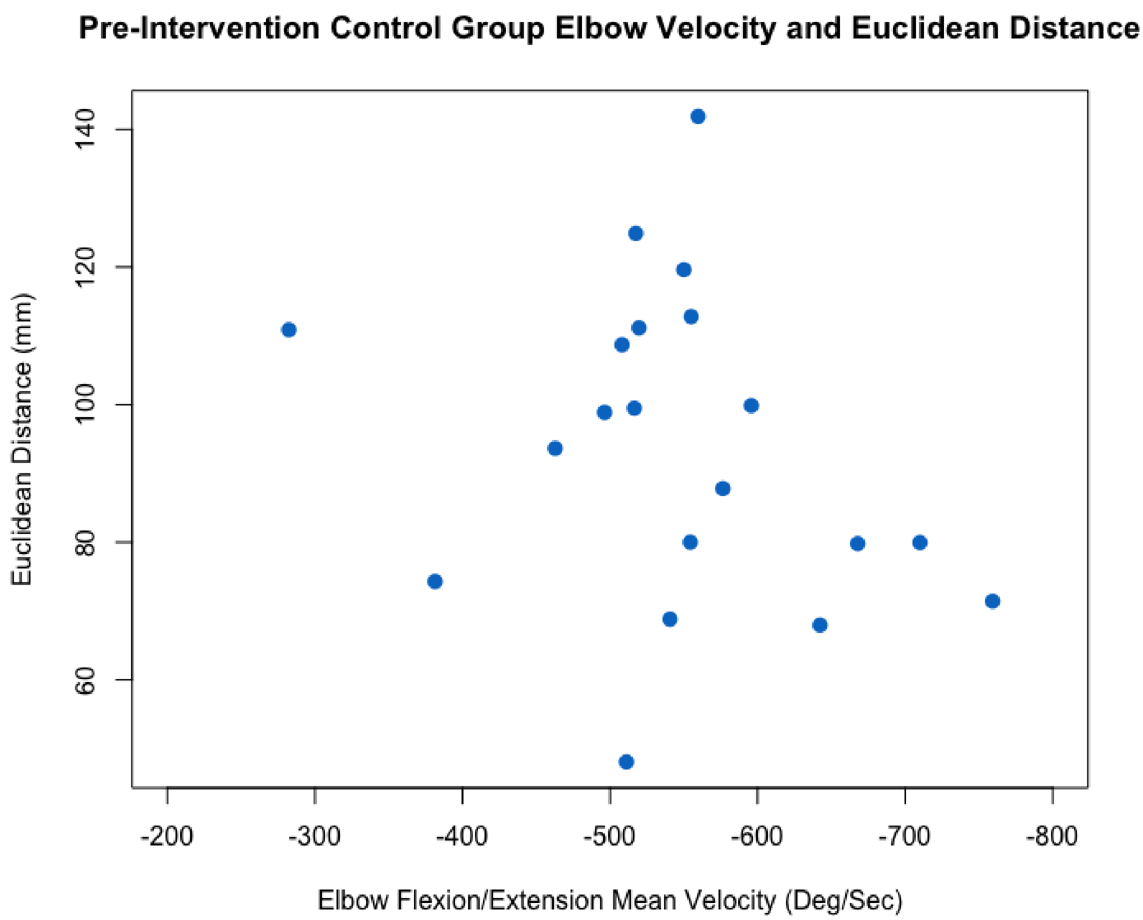

Figure 3.27: Mean pre-intervention control group resultant errors in mm plotted against pre-intervention throw time in seconds.

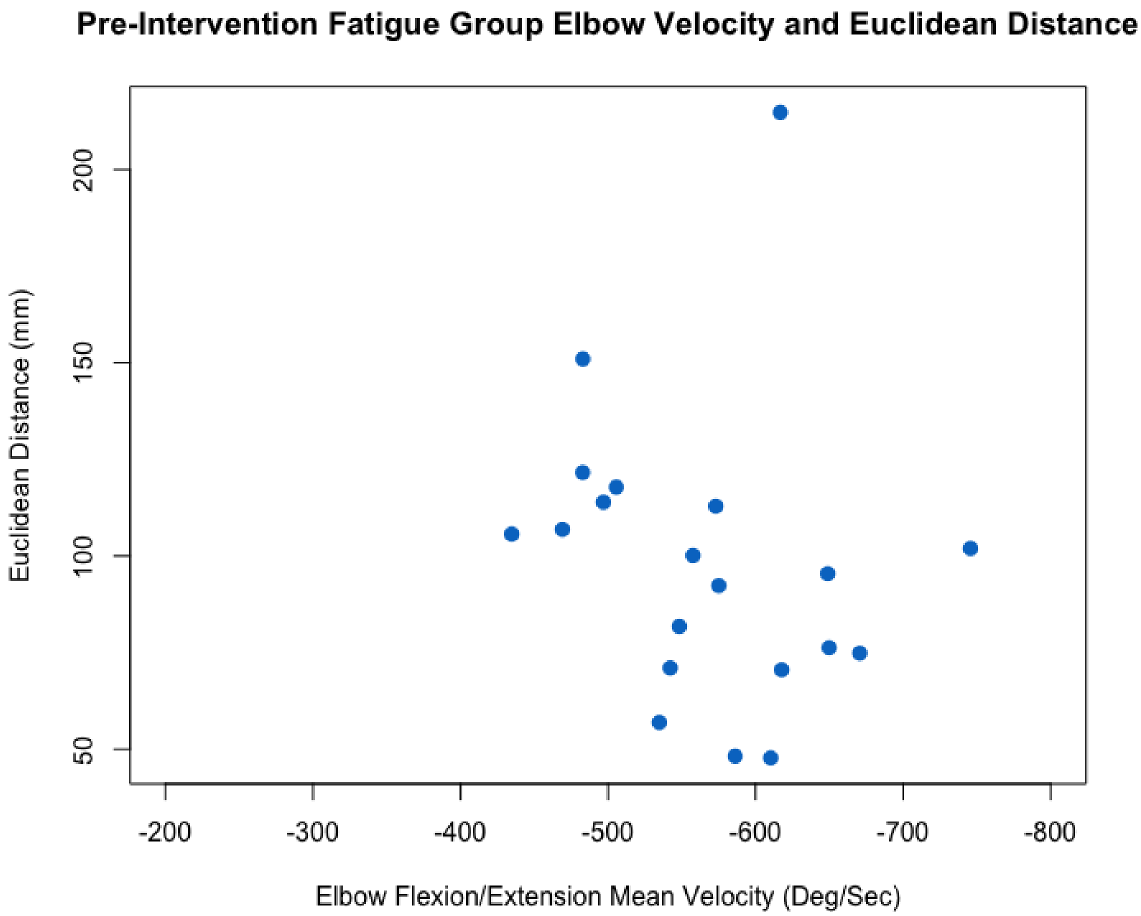

Figure 3.28: Mean pre-intervention fatigue group resultant errors in mm plotted against pre-intervention throw time in seconds.

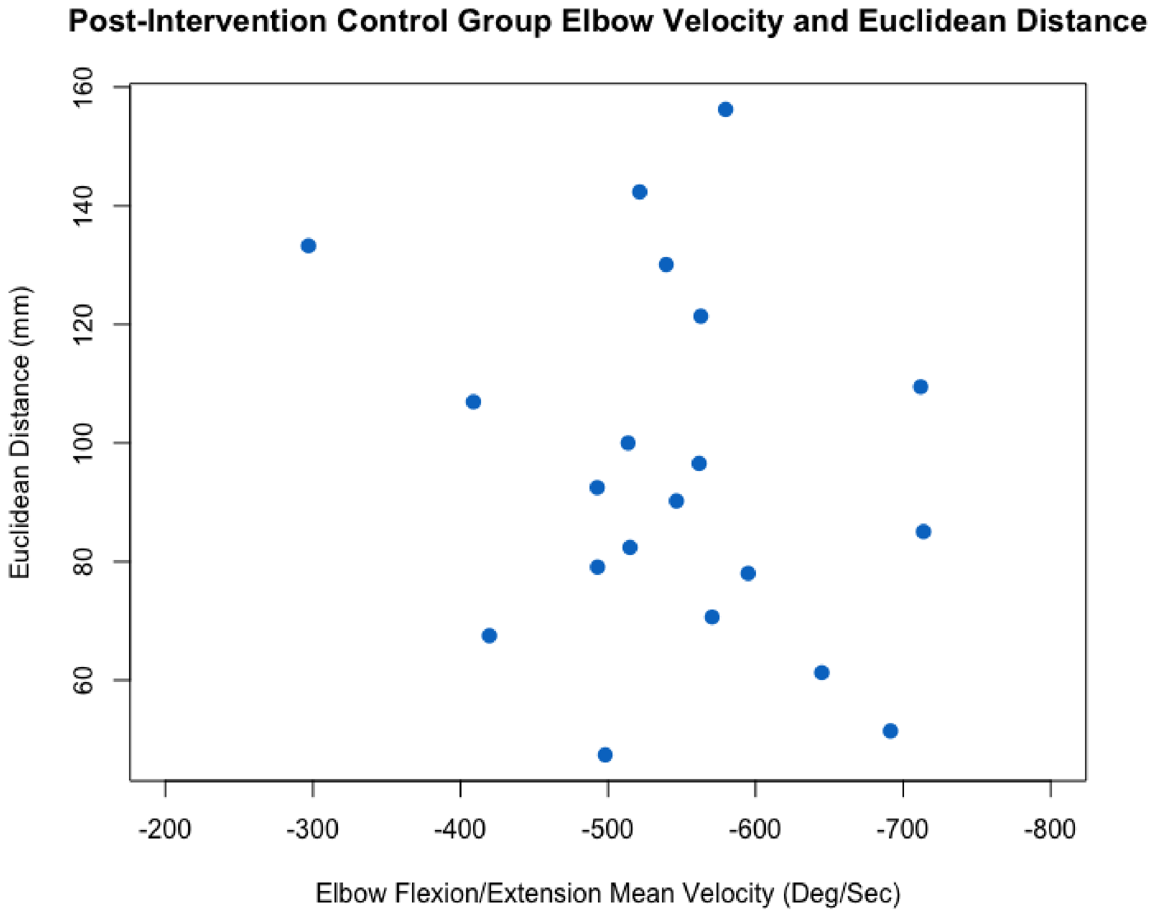

Figure 3.29: Mean post-intervention control group resultant errors in mm plotted against post-intervention throw time in seconds.

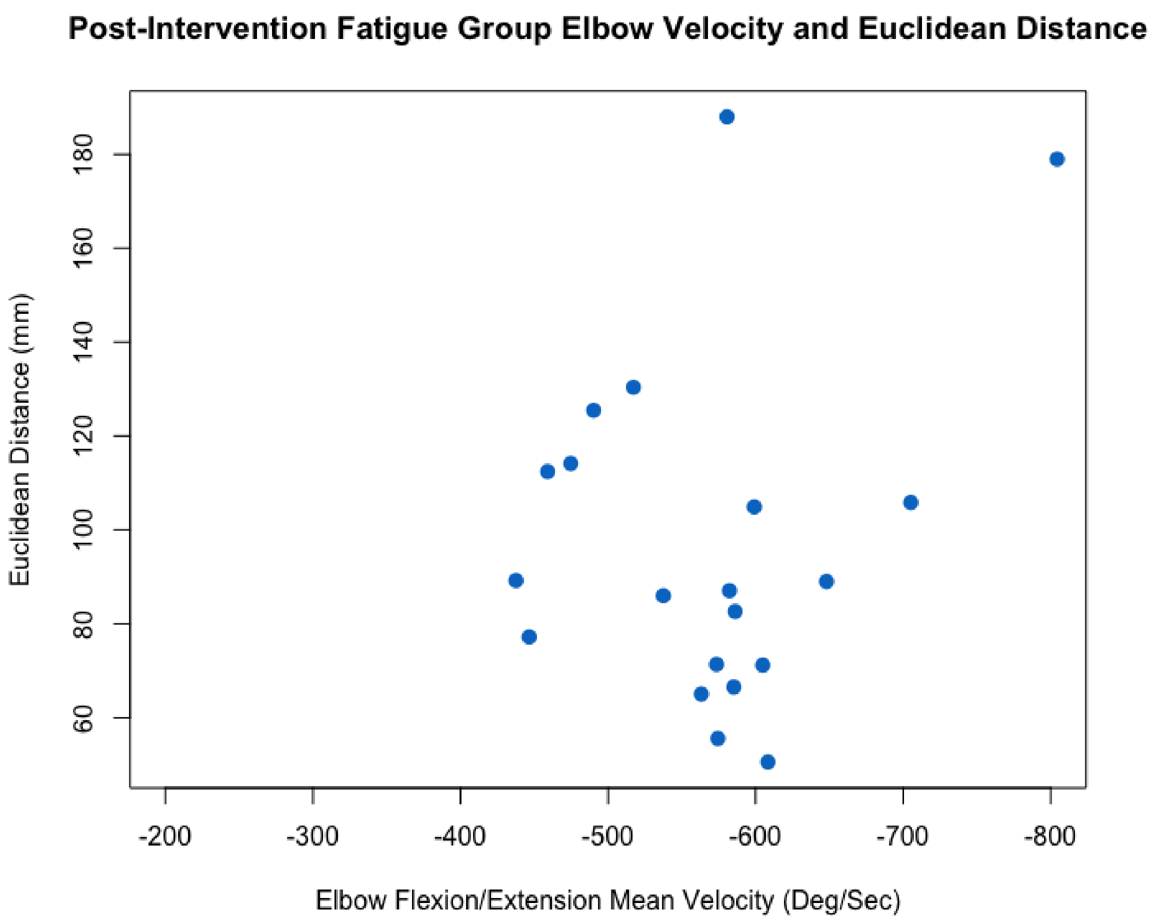

Figure 3.30: Mean post-intervention fatigue group resultant errors in mm plotted against pre-intervention throw time in seconds.

Chapter 4 General Discussion & Conclusions

4.1 Discussion

In this study, participants completed two sets of dart throws separated by an intervention task. Participants randomly assigned to the mental fatigue group participated in a mentally fatiguing cognitive task throughout the intervention period, whereas participants assigned to the control group participated in a task designed to minimize the impact of mental fatigue throughout the intervention. Kinematic variables indicating range of motion and angular velocities about joints of interest and dart landing position accuracy were monitored as main outcome variables throughout this study. As such, the primary purpose of this study was to examine the impact of mental fatigue on performance accuracy and upper limb kinematics in a novel perceptual motor task requiring aiming performance. It was hypothesized that:

1) Mental fatigue would lead to a decrease in performance accuracy.

2) Mental fatigue would lead to a speed-accuracy trade off in favour of maintaining dart throwing accuracy by decreasing movement velocity about the main axis of movement (flexion/extension about the elbow).

3) Mental fatigue would lead to significant changes in the kinematics of the primary upper limb joints utilized within the dart throwing motion.

4.1.1 Manipulation Check

As was expected, subjective ratings of mental fatigue were significantly higher throughout the Stroop task manipulation when compared to mental fatigue scores obtained from the control group. The results of this manipulation check indicate the success of the mental fatigue and control interventions. Additionally, the mental fatigue scores revealed no significant differences in reported baseline mental fatigue between groups. As such, this indicates no baseline differences in mental fatigue between groups were due to external factors. While both the Stroop task and control interventions appear to have been successful in achieving their respective goals, it is important to note slight increases from baseline in mental fatigue reported by the control group throughout the intervention. Nevertheless, considering the specific control protocol used, this was expected as some participants may have found it necessary to use cognitive energy to maintain focus of attention on the documentary. The use of an emotionally neutral documentary aids in reducing the risk of influencing the emotional state of participants. This is an important consideration as changes in emotional state might influence the impact of mental fatigue as the management of emotions has been observed to result in mental fatigue and positive emotions have been observed to decrease the impacts of mental fatigue (Baumeister, 2016). However, previous literature has demonstrated that the process of intentionally focusing attention can be mentally fatiguing (Baumeister, 2016). As such, if participants are uninterested in the content of the documentary, the cognitive energy that participants are required to exert to maintain focus throughout this intervention can be expected to result in some minor increases in mental fatigue. Thus, we believe that the slight increases in mental fatigue observed within the control group may be due to cognitive energy expended by a subset of participants who were uninterested in the content of the documentary presented. Notwithstanding, as mental fatigue was significantly elevated in the mental fatigue group with respect to the control group, any observed changes in movement and accuracy in the post-intervention dart set are most likely attributable to the introduction of mental fatigue.

4.1.2 Main Findings

Results obtained from kinematic data indicated no significant changes in any movement-based outcome variables with the exception of the shoulder end of movement angle, which demonstrated significant decreases in shoulder angle of elevation at end of movement among the fatigued group relative to control and baseline. To our knowledge, little research has been conducted examining efficacy of various movement patterns in dart throwing accuracy. However, due to these results, it is plausible that a lower end of range of motion shoulder elevation angle might have some association with decreased accuracy performance as recalibration rate also demonstrated moderate decreases associated with mental fatigue. Furthermore, this decrease in shoulder end of movement elevation angle might appear as a result of an attempt to conserve physical energy and mental energy in the presence of mental fatigue. As accurate and well-timed co-contraction of antagonistic muscles is likely required to slow shoulder flexion and prevent over flexion following a dart throwing motion, it is possible that while mentally fatigued, participants diverted mental and neuromuscular energy from the timely slowing of the shoulder flexion movement to other tasks deemed more important to accuracy performance. As little research has been conducted examining these biomechanical movement patterns and their impacts on performance accuracy in dart throwing, future research examining the dart throwing kinematic patterns would provide further insight into these findings. No other kinematic variables demonstrated changes associated with mental fatigue, including retraction angles, end of movement angles, and segmental velocities. These null findings were not expected, as it was hypothesized that mental fatigue would result in decreases in velocity along with significant modifications to retraction angle and end of movement angle to allow for the reduction of energy expenditure and increase accuracy performance. Therefore, the results of this study fail to reject the null hypothesis that mental fatigue changes movement patterns during accuracy performance to preserve energy and increase accuracy performance.

Accuracy data revealed no significant changes in vertical or horizontal accuracy associated with mental fatigue. As a significant decrease in accuracy in both the vertical and horizontal directions was hypothesized, these results were unexpected. Additional accuracy data revealed no significant change in resultant error associated with mental fatigue. As a significant decrease in resultant error in the presence of mental fatigue was hypothesized, these results were also unexpected. The results of resultant error, along with horizontal and vertical accuracy data suggest no observable overall changes in accuracy associated with mental fatigue. Recalibration rate data also revealed no significant changes in recalibration rate associated with mental fatigue. While the data revealed decreases in recalibration rate associated with mental fatigue within the mental fatigue group and increases in recalibration rate from pre-intervention to post-intervention among the control group. Although these results were non-significant, they do demonstrate the presence of some increases in accuracy between the first half of each dart throw cluster and the second half of each dart throw cluster from the pre-intervention to the post-intervention dart throwing set within the control group. No such increases in accuracy were observed within the mental fatigue group, instead, decreases in recalibration rate were observed. This indicates a decreased capacity for self-correction among mentally fatigued participants. As a decrease in recalibration rate associated with mental fatigue had been hypothesized, these results were as expected. Considering the inconclusive results obtained from all accuracy-based variables examined, the results of this study fail to reject the null hypothesis that mental fatigue would decrease performance accuracy in dart throwing tasks.

Results obtained through statistical correlations between elbow mean velocity and resultant error for the pre-intervention and post-intervention time points individually within the fatigue and control group all revealed no significant correlations. As a speed-accuracy trade off in the presence of mental fatigue was hypothesized, these results were unexpected. Therefore, the hypothesis that mental fatigue would lead to a speed-accuracy trade off in the presence of accuracy-based tasks was rejected.

One potential explanation for the lack of significant changes reported among all main outcome variables observed within this study is the complexity of the chosen accuracy task. Dart throwing requires a complex series of well-timed movements involving many segments of interest. The complexity of this task is particularly pertinent among novice dart throwers who have not yet been provided with the opportunity to develop a strategy to maintain accuracy through a comfortable movement pattern as might be observed among more experienced dart throwers (Nasu, 2014). This complexity of movement can be assumed to lead to substantial variance in movement patterns and accuracy performance within and between participants. Thus, it is possible that this increase in variance might conceal any impacts that mental fatigue would otherwise have on main outcome variables. (Figure 4.1)

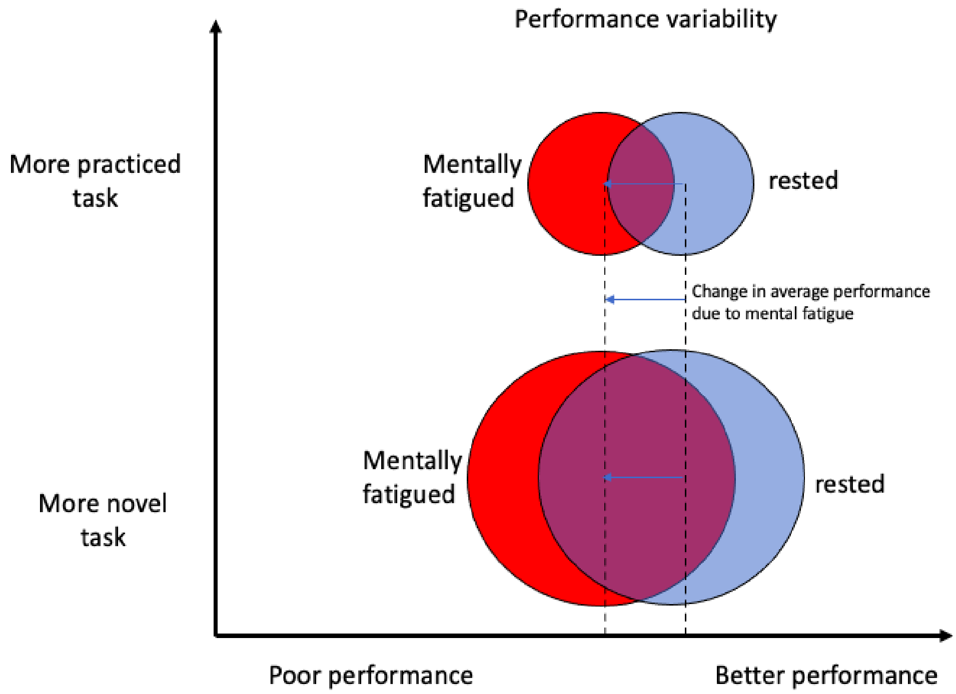

Figure 4.1: Conceptual diagram demonstrating the theoretical impact of performance variability and task practice on observable changes due to mental fatigue. Assuming a constant decrease in performance due to mental fatigue, it is possible that the extreme performance variability exhibited by this complex novel task masked any mental fatigue performance decrements. This effect may not have been so substantial in a more practiced group of subjects, who would likely demonstrate smaller overall performance variability.

Much of the variation observed within kinematic data was a result of the considerable variety of movement strategies adopted by various individual participants. Two generalized movement strategies could be observed among participants. The first of these strategies is a sideways facing strategy. This strategy relies heavily on elbow flexion/extension along with shoulder horizontal adduction/abduction and wrist ulnar/radial deviation with the participant's trunk rotated 90° relative to the dart board. Other participants relied on a forward-facing strategy which consisted of the use of elbow flexion/extension and wrist flexion/extension. Future research might benefit from restraining participants to one or both of these strategies respectively in order to decrease variability among the data set.

4.1.3 Limitations and Assumptions within Study Protocol

Limitations presented by inertial measurement units (IMUs) used should be considered in the analysis of the results presented. As IMUs require the attachment of surface level trackers on each segment of interest, the nature of these trackers have the potential to restrict or discourage movements within the full range of motion. However, substantial caution was taken to ensure trackers placed no limitations on participant's movement. This included the secure attachment of all trackers along with verbal confirmation from participants indicating that trackers were not interfering with the range of motion used for dart throwing. Additionally, as participant's foot placement was restricted to a designated area, some participants may have been required to modify their stance to accommodate the allocated space. However, these restrictions were necessary to the study design as they allowed for the insurance of a standardized dart throwing location and therefore allowed for inter-participant comparability.

There is a potential that the variability observed in participant's movement strategies impacted the detectability of the effects of mental fatigue on movement strategy as previously mentioned. While it was valuable to instruct participants to utilize self-selected movement strategies as this allowed for more accurate measurements of accuracy performance. This provides results which can be comparable to the impacts that mental fatigue might have on performance in complex aiming based tasks such as dart throwing. However, future research might benefit from the evaluation of changes in kinematic behaviour in accuracy-based tasks associated with mental fatigue while restricting potential movement strategies. This might include restricting participants to a shoulder flexion-based throwing strategy during dart throwing tasks. As such, complexity and variability between participant's kinematic behaviour would be minimized thus allowing for more accurate identification of observable changes.

Additionally, due to the nature of the visual analog scale utilized to monitor mental fatigue, there is a potential for variability between participant's subjective responses. However, precautions were taken to mitigate the impact that this variability might have on the data to reduce the potential for inaccuracies in the findings of this study. The visual analog scale was utilized as the predominate manipulation check as it allows for a subjective observation of mental fatigue. While it would present some value to include an objective reporting of performance metrics such as what might be obtained from the comparison of response time and accuracy of responses in an incongruent Stroop task within a fatigue group to response time and accuracy in a congruent Stroop task within a control group. This strategy was not utilized to avoid the introduction of additional mental fatigue due to the conscious focus of attention required in the performance of a congruent Stroop task. Mental fatigue was observed at baseline and throughout the intervention task in both groups to allow for a comparison of baseline and trends in mental fatigue between groups. This allowed for the data to be monitored for any potential group differences in participant's likelihood to subjectively identify themselves as experiencing more or less mental fatigue. As no significant differences between groups were observed in subjective mental fatigue at baseline with the fatigue group reporting significantly higher mental fatigue at all other time points throughout the intervention, it can be assumed that any group differences in likelihood to report higher or lower subjective mental fatigue would be negligible.

All participants were assumed to be representative of a novice dart throwing population as this study sought to examine the impacts of mental fatigue on novel dart throwing tasks. Demographic information collected from participants screened for previous dart throwing experience and only individuals considered novices were recruited for participation. However, demographic information collected did not screen for baseline dart throwing skill level or previous experience with other accuracy-based sports which might provide translatable skills. While this might allow for some variation in baseline dart throwing skill levels within the participant population, as participants were randomly allocated to control and fatigue groups, it is unlikely that this variation would significantly impact the results of this study. Moreover, participants in this study consisted of undergraduate and graduate students aged 18-30 years. These participants were assumed to be representative of the general population, however, future research should seek to explore the replicability of these results among younger and older populations along with other populations of interest such as workforces and professional athletes.

4.1.4 Additional Findings

BTSCS scores detected no significant intergroup differences in trait self-control. Trait self-control was identified as an important potential confounding variable within this study's protocol as researchers have theorized that mental fatigue may result from the depletion of a limited reservoir of self-control through the performance of cognitively demanding tasks as in the ego-depletion theory (Baumeister et al., 1998; Tangney et al., 2004). As such, individuals who score lower in trait self-control may be more susceptible to the carryover effects of mental fatigue. Consequently, the absence of significant inter-group variances in trait self-control suggests no imbalance in susceptibility to mental fatigue between groups.

While a slightly lower TSES score was observed in the mental fatigue group as compared to the control group, this difference was not significant. As such, this study presented no evidence that mental fatigue led to a change in self-efficacy to perform a dart throwing task. Self-efficacy refers to an individual's belief in their ability to perform the actions necessary to achieve a goal and has been associated with energy expenditure towards goal achievement (Bandura, 1977, 1986, 1997). The results of this study suggest that mental fatigue might have negligible impacts on self-efficacy in the performance of accuracy based physical tasks whereas some research has observed decreases in task self-efficacy associated with mental fatigue when performing endurance based tasks (Graham & Bray, 2015; Graham et al., 2017). Moreover, this suggests that task self-efficacy had a negligible impact on all main outcome variables. Yet, as small but statistically nonsignificant inter-group differences in TSES scores were observed, further studies might seek to examine the replicability of this relationship given findings from previous research (Graham & Bray, 2015).

Reported IMI scores presented no evidence of inter-group differences in intrinsic motivation at baseline. However, near significant inter-group differences were observed post-intervention. Results demonstrated an increase in intrinsic motivation from baseline to post-intervention in the control group whereas a decrease in intrinsic motivation was observed in the mental fatigue group during the same period of time. While these results were not of statistical significance, they present some evidence of a potential link between decreased intrinsic motivation, accuracy based physical task performance, and mental fatigue. As such, a decrease in intrinsic motivation presents as a potential mechanism through which mental fatigue might impact performance in accuracy-based tasks (Baumeister & Vohs, 2007; Ryan & Deci, 2008). Although these results are statistically nonsignificant, future studies might seek to examine the replicability of this relationship given previous findings examining motivation and physical task performance (Graham et al., 2014b).

Overall, subscales of the NASA-TLX presented interesting findings which can provide some important insights into the impacts of mental fatigue on accuracy-based tasks. The NASA-TLX mental demand subscale presented near significant evidence supporting the presence of a relationship between mental fatigue and an increase in subjective mental demand experienced during accuracy based physical performance tasks in the fatigue group. While post hoc analyses indicated near significant increases in subjective mental demand associated with time within the control group and significant increases in subjective mental demand associated with time in the fatigue group. Previous literature has suggested that mental fatigue leads to a temporary decrease in cognitive energy resulting in decreased cognitive performance (Baumeister et al., 1998). If it can be assumed that this would result in an increase in subjective mental demand, the results of this study might suggest that the performance of accuracy based physical tasks such as dart throwing might require the use of cognitive energy in a manner similar to other tasks which are traditionally understood to be mentally fatiguing. However, as the interaction effects of the ANOVA presented as statistically nonsignificant, future studies might seek to examine the replicability of this relationship. The results of this subscale indicate that mental demand was one of the subscales of the NASA-TLX that was the most highly impacted by mental fatigue.

Other subscales of the NASA-TLX indicated less evident or no changes associated with mental fatigue. The NASA-TLX physical demand subscale presented no evidence supporting the presence of a relationship between mental fatigue and changes in perceived physical demand associated with accuracy based physical task performance. These results are similar to results observed among other subscales of the NASA-TLX.

Similar to the physical demand subscale of the NASA-TLX, the NASA-TLX temporal demand subscale presented no evidence supporting the presence of a relationship between mental fatigue and changes in perceived temporal demand associated with accuracy based physical task performance. Changes in temporal demand associated with mental fatigue were unlikely as participants were given no specific time allotment for the completion of both the pre-intervention and post-intervention dart throwing set. Consequently, the absence of significant variances in temporal demand suggests the presence of no time-based confounders. Comparable results can be observed within other subscales of the NASA-TLX.

As seen in other NASA-TLX subscales, the NASA-TLX performance subscale presented no significant evidence of an inter-group difference in perceived performance following the interventions. Although no significant changes in resultant error performance were observed in either group, non-significant but observable inter-group differences in recalibration rate were observed. These results indicate that participants were likely unaware of these changes. This posits interesting implications for the impact of mental fatigue on the individual’s ability to accurately evaluate aiming performance.

Nevertheless, future studies might seek to examine the replicability of this relationship. These results correspond with the results of the NASA-TLX effort subscale.

The NASA-TLX effort subscale scores revealed no significant evidence of inter-group differences in perceived effort. Consequently, the absence of significant variances in subjective effort suggests the presence of no effort-based confounders in this experimental design. However, while these results imply no increases in effort associated with mental fatigue, this does not appear to correspond with subjective frustration.

The NASA-TLX frustration subscale scores revealed interaction effects approaching significance with a post hoc analysis indicating no significant changes in subjective frustration associated with time among the control group and significant increases in subjective frustration associated with time in the mental fatigue group. This indicates a potential increase in frustration rate associated with mental fatigue along with the slight decrease in recalibration rate associated with mental fatigue in the fatigue group.

4.1.5 Future Directions

Future research might seek to examine the complex nature of dart throwing kinematic patterns and their association with mental fatigue by evaluating the percent contribution from each degree of freedom of interest about the shoulder, elbow, and wrist to the overall range of motion of the dart. Additionally, the inclusion of a measured time of dart release in future study protocols would allow for a more nuanced investigation of the complexity of this relationship. This would allow for the examination of timing and location of dart release relative to retraction dart location.

4.2 Conclusions

Results obtained from kinematic data indicated no significant changes in any movement-based outcome variables with the exception of the shoulder end of movement angle of elevation. Additionally, no significant changes were observed in accuracy-based variables although recalibration rate data showed observable but non-significant changes demonstrating a potential decrease in recalibration rate associated with mental fatigue. Due to the complex nature of accuracy-based tasks such as dart throwing, it is possible that any potential impacts that mental fatigue might have on accuracy or movement might be made undetectable as a result of the significant variance within and among individual participant's accuracy and movement performance. As such, this study provides some evidence indicating that mental fatigue might have negligible impacts on performance accuracy and movement during complex novel accuracy-based tasks. However, as near significant decreases in recalibration rates were associated with mental fatigue, it can be suggested that mental fatigue might impact accuracy performance to a degree that is not evident among novice individuals performing complex accuracy-based tasks as performance accuracy in these situations may be prone to significant variability. Nonetheless, this impact may become evident in the performance of less complex accuracy-based tasks (such as reaching or pointing tasks) or among highly trained individuals (such as competitive athletes or individuals working in skilled trade jobs requiring the regular performance of repetitive aiming tasks) with the assumption that highly trained individuals would display decreased variability in kinematic patterns and accuracy when compared to novice participants. This assumption is justified because long term practice has been observed to increase accuracy and reduce variability of either timing of dart release or hand trajectory among dart players (Nasu et al., 2014).

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APPENDICS

Appendix A
Statistical
Assumption Check

		Homogeneity of Variance		Sphericity	Normality	
	Transformation Used	Pre - Intervention	Post - Intervention		Pre - Intervention	Post - Intervention
Time Variables						
Throw Time		0.223	0.137	1	<0.001*	<0.001*
Throw Time Transformed	1/x	0.283	0.242	1	0.291	0.763
Prep-Time		0.489	0.546	1	0.205	0.487
Elbow Variables						
Elbow Flexion/Extension Retraction Angle		0.003*	0.001*	1	0.122	0.155
Elbow Flexion/Extension End of Movement Angle		0.24	0.15	1	0.075	0.491
Shoulder Variables						
Shoulder Adduction/Abduction Retraction Angle		0.105	0.215	1	0.929	0.275
Shoulder Adduction/Abduction End of Movement Angle		0.174	0.014*	1	0.466	0.154
Shoulder Adduction/Abduction End of Movement Angle Transformed	x^2	0.292	0.051	1	0.087	0.266
Shoulder Flexion/Extension Retraction Angle		0.452	0.866	1	0.801	0.069
Shoulder Flexion/Extension End of Movement Angle		0.653	0.593	1	0.383	0.216
Wrist Variables						
Wrist Ulnar/Radial Deviation Retraction Angle		0.272	0.486	1	0.63	0.972
Wrist Ulnar/Radial Deviation End of Movement Angle		0.955	0.8	1	0.709	0.746
Wrist Flexion/Extension Retraction Angle		0.259	0.179	1	0.327	0.676
Wrist Flexion/Extension End of Movement Angle		0.678	0.315	1	0.635	0.64
Velocities						
Elbow Flexion/Extension Velocity		0.622	0.578	1	0.238	0.068
Shoulder Adduction/Abduction Velocity		0.656	0.896	1	0.139	0.225
Shoulder Flexion/Extension Velocity		0.394	0.649	1	0.591	0.591

Wrist Ulnar/Radial Deviation Velocity		0.788	0.567	1	0.21	0.122
Wrist Flexion/Extension Velocity		0.989	0.887	1	0.708	0.786
Accuracy Variables						
Horizontal Distance		0.766	0.812	1	0.042*	0.889
Vertical Distance		0.47	0.618	1	0.093	0.044*
Resultant Error		0.245	0.547	1	0.003*	0.034*
Recalibration Rate		0.705	0.568	1	0.004*	0.623
Recalibration Rate Transformed	log10(x)	0.242	0.812	1	0.027	0.952
Manipulation Check						
Brief Trait Self Control Scale		0.445			0.251	
Task Self Efficacy Scale		0.245			0.017*	
Task Self Efficacy Scale Transformed						
Intrinsic Motivation Inventory		0.065	0.028	1	<0.001*	<0.001*
Mental Fatigue		0.377			0.383	
NASA - TLX Mental Demand Subscale					<0.001*	0.077
NASA - TLX Physical Demand Subscale					<0.001*	0.001*
NASA - TLX Physical Demand Subscale Transformed		0.706	0.234	1	0.054	0.267
NASA - TLX Temporal Demand Subscale					<0.001*	<0.001
NASA - TLX Temporal Demand Subscale Transformed		0.279	0.302	1	0.042*	0.053
NASA - TLX Performance Subscale		0.325	0.28	1	0.431	0.115
NASA - TLX Effort Subscale					0.232	0.04*
NASA - TLX Frustration Subscale					<0.001*	0.004*
NASA - TLX Frustration Subscale Transformed	log10(x)	0.969	0.632	1	0.002	0.005

Appendix B

Informative Email

Hi [insert participant name here],

Thank you for showing interest in being a participant for our research study. Provided in this email is additional information about the research study and a copy of the letter of informed consent that, should you decide to participate, will be provided for you to sign at the beginning of the experiment (i.e., before you start). Please remember that by showing this initial interest you are under no obligation to follow through with participation and will not suffer any consequences by deciding not to participate. Additional information about the consent process, options for withdrawal, compensation, benefits, potential risks, participant rights, and other details of the experiment are outlined in the attached letter of informed consent.

In this research study, you will perform four data collection sessions (each no longer than 1 hour) on different days separated by at least 24 hours. The first three sessions must be completed within 7 days, and the final session needs to be completed 48 hours after the third session. In these sessions you will perform a series of dart throws (maximum 60 in one trial) while aiming at a dartboard from a standardized distance. We will measure your gaze behaviour (i.e., what you are looking at) and your movements when throwing the darts. In trials 1-3, you will also perform a cognitive task (incongruent stroop task or watch a nature documentary). Some risks are involved with this research study. We suggest that you thoroughly review the "Potential Risks and Discomforts" section of the informed consent form before agreeing to participate. We also suggest that you bring closed-toed shoes to the trials and take extra precaution when handling the darts to mitigate some of these risks.

We also ask that you keep the same routine before each trial. This is of particular importance when considering the consumption of caffeinated beverages. For instance, if you drink coffee 90 minutes before trial 1, we ask that you follow this same routine for trials 2-4.

Please review the following eligibility criteria for participation in this study:
Eligibility Criteria: Healthy adult (age = 18-30) individuals
Exclusion Criteria: Anybody who has experience or has played beyond a recreational level for darts. Additionally, those who require prescription glasses for everyday use without the ability to wear prescription contact lenses or are colour blind. Along with individuals with any injuries/symptoms that may prevent completion of a cognitively challenging task and/or up to 60 dart throws in one sitting.

We will be attaching motion tracking devices directly to your shoulder blades and upper sternum, if necessary, please arrive with a tank top, sports bra or other top which will allow access to these areas. If for any reason you are unable to fulfill this requirement, please let us know and we will do our best to accommodate.

Please read the attached letter of informed consent before deciding to participate. Please complete the attached informed consent and pre-study questionnaire forms and return it to the researchers before arriving for the first visit. Once again, by showing this initial interest you are not obligated to participate in this study. Please do not hesitate to email us (matthew.mccue@ontariotechu.net and sarah.fitzgerald2@ontariotechu.net) if you have any questions or need clarification on any parts of this study.

Thank you for your initial interest and we hope to hear from you soon.

Sincerely,

Sarah Fitzgerald, BSc
MHSc Student, Faculty of Health Science
Ontario Tech University
Email: Sarah.fitzgerald2@ontariotechu.net

Matt McCue, MHSc
PhD Student, Faculty of Health Sciences
Ontario Tech University
Email: Matthew.mccue@ontariotechu.net

This study has been reviewed by Ontario Tech University Research Ethics Board 16238 on September 17th 2021

Appendix C

Pre-Study Questionnaire

Pre-study Questionnaire

Mental fatigue effects during performance and learning of a perceptual-motor task

Participant Demographics

Date of Birth: ________ ________ ________
Day *Month* *Year*

Sex: Female Male Other (specify below)

Participant Information

1. Do you have 20/20 vision?

Yes No

If no, do you wear corrective contact lenses?

Yes No

Do you require glasses for optimal performance in aiming tasks (i.e., dart-throwing, horseshoes, sport-specific aiming)?

Yes No

2. Please indicate your experience with throwing darts

- [ ] Have played or am playing competitively (i.e., competing at least once a month)
- [ ] Have competed recreationally (i.e., organized tournaments at a restaurant)
- [ ] I play recreationally (i.e., have played more than 10 times but in informal settings)
- [ ] Rarely play (less than 10 times ever)
- [ ] Never played

7. Are you currently experiencing any health concerns that may prevent you from throwing darts or make performing cognitive tasks difficult?

Yes No

If yes, please specify: ______________________________

8. Is there any reason you would not be able to perform a task which would require you to distinguish between images of differing colours?

Yes No

If yes, please specify: ______________________________

9. Would you like to be emailed future communications of this research? This includes but is not limited to: conference abstracts, conference presentations, academic publications, and other mediums of scientific communication (NOTE: All dissemination of this data will be group aggregate meaning that no one will be able to deduce your individual results).

Yes No

Disclaimer and Signature

I certify that my answers are accurate and adequately depict my dart-throwing experience and current health status.

Signature: ______________________ ***Date:*** __________

Appendix D

Informed Consent

Consent Form to Participate in a Research Study

Title of Research Study: Comparing the effects of different cognitive tasks on dart throwing accuracy

Name of Principal Investigator (PI) and email: Dr. Nick Wattie (Nick.Wattie@ontariotechu.ca)

Names of Student Leads and emails: Matt McCue (matthew.mccue@ontariotechu.net) and Sarah Fitzgerald (Sarah.Fitzgerald2@ontariotechu.net)

Names of Co-Investigators and emails: Dr. Nicholas La Delfa (Nicholas.LaDela@ontariotechu.ca) and Dr. Jeffrey Graham (Jeffrey.Graham@ontariotechu.ca)

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

External Funder/Sponsor: None

All aspects of this study 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

Introduction

You are invited to participate in a research study entitled "Comparing the effects of different cognitive tasks on dart throwing accuracy." 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 reviewed by the Ontario Tech University Research Ethics Board [insert REB assigned #] on [insert date].

Purpose and Procedure:

Purpose:
This study is trying to understand how different cognitive tasks affect performance and learning, particularly the performance and learning of a task that requires visual attention and movement. A common task that requires little explanation yet incorporates visual processing and movement is dart throwing. You have been invited to participate in this study because you are a healthy individual that has 20/20, or corrected to 20/20 vision without the need for prescription glasses, and have never played darts above a recreational level.
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 and Appendix Y carefully before also considering the following procedures that are specific to this experimental study.

If you choose to voluntarily participate in this study, the following methods will be followed:

You will be asked to bring a mask to campus. Upon arrival, you will be equipped with mobile eye tracking technology (very similar in appearance and weight to prescription glasses without the lenses) and instrumented with non-invasive sensors so we can track the movement of your upper extremities. The sensors will be affixed to your skin with tape, after the skin surface is shaved using a disposable razor and cleaned using alcohol wipes.You will then perform 30 dart throws, while aiming at a dartboard from a standardized distance. You will then be asked to complete a cognitive task described to you during the day of the study. This task requires no physical effort but it does require your visual and cognitive attention. Once the task is completed, you will throw 30 more darts at the dartboard. This will complete the first visit and we estimate that it will take approximately 45-60 minutes to complete.

Following the first visit, we will ask you to return to the laboratory 3 more times. The 2nd and 3rd visit will be slightly different and require less of your time. For these visits, you will arrive at the laboratory and we will again equip you with the mobile eye tracker. However, this time you will complete the cognitive task first, and then throw 30 darts. We estimate these visits will require 30-45 minutes of your time. The 2nd and 3rd visit will need to be completed within seven days from the first visit, with 24 hours minimum required between each visit.

Finally, we will ask you to come in for the 4th visit 48 hours after you complete the 3rd visit. The 4th visit will require you to be equipped with the mobile eye tracker and asked to throw 60 darts at the dartboard. We estimate this visit will require 30-45 minutes of your time. This will conclude your participation in the study.

The entire process will take approximately three hours spread over four different trips to the laboratory. Following the first visit, we will ask that you complete the next two visits in seven days, and the final visit 48 hours after the 3rd visit.

All research will be conducted at Dr. Nick Wattie's Lab: U5 67 – 2000 Simcoe Street North, Oshawa, Ontario, L1G0C5.

Visit	Study procedure/tests/interventions	Duration of visit
Visit 1	· Equipped with mobile eye tracker, non-invasive sensors, and asked to stand motionless on a force plate for 30 seconds. · Complete motivation inventory (short survey) · Perform 30 dart throws · Complete ratings of perceived physical and mental exertion, NASA Task Load Index, and the sport anxiety scale-2 (short surveys) · Cognitive task · Complete ratings of perceived mental exertion, motivation, and task self-efficacy (short surveys) · 30 more dart throws · Complete ratings of perceived physical and mental exertion and Nasa Task Load Index (short surveys)	45-60 minutes
Visit 2	· Equipped with mobile eye tracker, non-invasive sensors, and asked to stand motionless on a force plate for 30 seconds. · Complete ratings of perceived physical and mental exertion, NASA Task Load Index, and the sport anxiety scale-2 (short surveys) · Cognitive task · Complete ratings of perceived mental exertion, motivation, and task self-efficacy (short surveys) · 30 dart throws · Complete ratings of perceived physical and mental exertion and Nasa Task Load Index (short surveys)	30-45 minutes

Visit 3	· Equipped with mobile eye tracker, non-invasive sensors, and asked to stand motionless on a force plate for 30 seconds. · Complete ratings of perceived physical and mental exertion, NASA Task Load Index, and the sport anxiety scale-2 (short surveys) · Cognitive task · Complete ratings of perceived mental exertion, motivation, and task self-efficacy (short surveys) · 30 dart throws · Complete ratings of perceived physical and mental exertion and Nasa Task Load Index (short surveys)	30-45 minutes
Visit 4	· Equipped with mobile eye tracker, non-invasive sensors, and asked to stand motionless on a force plate for 30 seconds. · Complete ratings of perceived physical and mental exertion, NASA Task Load Index, sport anxiety scale-2, motivation, and task self-efficacy (short surveys) · 60 dart throws	30-45 minutes

Potential Benefits:

As a participant in this study, you will be given the option to obtain any communications of our findings (option to opt-in for these communications is located on the pre-study questionnaire). The data found in the communications may be used to contextualize what your eyes are actually fixating on and how you are moving in space during a dart-throw. This information may be used to enhance your dart throwing ability, or transferred to other tasks that require visual aiming.

An additional benefit to participating in this research is the exposure to graduate level research. Matt McCue will be using this data as the first stage of his PhD thesis, and Sarah Fitzgerald will be using this study as her master's project. If you are contemplating a career in academia/graduate school, or are simply curious about what this career pathway entails, this experience will certainly be of value.

As compensation for your time spent participating in this study, you will be offered 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). By participating in this study, you will be offered 2% extra credit to be put towards the final grade of your selected course. If you withdraw from the study for any reason, you will receive 0.5% extra credit for every data collection session that was started.

Beyond direct benefits to you as a participant, this study will also address a significant gap in the scientific literature. Currently, it is well established that performance and skill acquisition in perceptual-motor tasks (like dart throwing) requires a constant pairing of visual information and complex movements. However, it remains unclear how a learning environment may affect the development of this pairing. Your participation in this study will help us address such unknowns.

Potential Risks and Discomforts:

As the COVID-19 pandemic continues to affect everyone in the province of Ontario (and of course nationally and internationally), there are a number of risks associated with in-person research. One of these COVID-19 associated risks is the possibility that the virus is transmitted from/to you (the volunteer participant) from/to the research team. To mitigate the risk of transmission, we will take a number of precautions; all laboratory material that you will come in contact with will be sanitized before and after each use, and we will ensure that you have you are the only user of certain materials (i.e., printed surveys, cognitive task, disposable razor) where appropriate. Further, we will limit the number of researchers in the laboratory to two, with each researcher wearing an N95 mask, face shield and gloves. Physical distancing of six feet will be mandatory at all times with the researchers only breaching the six feet to calibrate and troubleshoot study-related technology. We will also ask every participant to fill out a pre-screening form prior to coming to the laboratory, and we will trace contact with each participant so that should an outbreak occur, you will be immediately notified by the research team. An additional COVID-19 associated risk with in-person research is our requirement of you to commute to the university. We strongly suggest that you drive or walk yourself to campus (if possible), and you will be given a parking voucher from the research team if the parking gates require payment at the time of your participation. Finally, there is also the possibility that you are more vulnerable due to the nature of the pandemic. These vulnerabilities can be psychological, economic, physical, or social. At this point, we would like to remind you of the voluntary nature of your participation - you are able to withdraw from the study at any point if these vulnerabilities begin to outweigh the benefits of participating. Please read the COVID-19 Related Information section for further information regarding the risk mitigation strategies we are employing to minimize the risk of COVID-19 exposure during this research study.

Another possible risk associated with the study is the chance you accidentally grab the sharp end of the darts or drop the dart. We will ensure that the darts are handed to you with the sharp end facing away from you. We also suggest that you wear close-toed shoes to prevent the risk of dropping the dart on your feet. Additionally, this study will require you to throw 180 darts spread over four visits. We ask that you only agree to participate if you believe 180 dart throws—spread over four different days—will not cause or aggravate any injuries. Another potential risk may be that you experience a low risk skin irritation caused by EMG electrodes or kinematic system markers. If irritations occur, these complications are not serious and should subside within days.

Although there may be minor risks associated with participating, you are allowed to withdraw from the study at any point should you experience discomfort.

COVID-19 Related Information

At this point in time, the risk of the Omicron variant of concern in Ontario is high and the risks of further transmission, severe disease, reinfection, and breakthrough infection in Ontario is moderate with a high degree of uncertainty. The overall risk assessment may change as new evidence emerges (Public Health Ontario, December 2021.pdf). We will keep you informed on these changes.

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

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

i. 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).

ii. 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

iii. 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.

iv. 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.

v. 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.

<u>Use and Storage of Data:</u>

All information collected during this study, including your name, date of birth, gaze behaviour data, kinematic data, dart-throwing performance, and performance on cognitive tasks 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.

<u>Confidentiality:</u>

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. Please note that confidentiality cannot be guaranteed while data is in transit over the internet.

Please note that the security of e-mail messages is not guaranteed. Messages may be forged, forwarded, kept indefinitely, or seen by others using the internet. Do not use e-mail to discuss information you think is sensitive. Do not use e-mail in an emergency since e-mail may be delayed.

All data collected and contained in the study will be treated as confidential. For this data set, all personal identifiers will be removed from the data set, and the subjects will be organized by number rather than names. This practice ensures that it is not possible to trace any data back to a specific individual. You consent to have your data used for the purpose of research in the form of a thesis, as well as academic outputs such as: presentations, conferences, and peer reviewed publications. All results of the study will be presented as aggregate data, and no individual will ever be presented. All qualitative and quantitative data will be compiled and stored on secureservers, password protected computers and files that only the student leads—Matt McCue and Sarah Fitzgerald—will have access to. No individual data will be presented during the dissemination of the results. Data will be stored for up to 5 years, after which point data will be destroyed. 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. However, this information will be separated from data that is collected during the study to ensure all data collected and contained in the study is unlinked to your personal contact information. 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.

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, relationship with the institution, grades in a course, or relationship with any member of the research team. 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:

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 and you do not need to offer any reason for making this request. Once data collection is complete, you may withdraw your data from this study for any reason until June 1st, 2022 (date may change to later depending on the restrictions placed by the pandemic). Your decision to stop participating in the study, or refusal to answer particular questions will not affect your relationship with the Principal Investigator, student leads, or Ontario Tech University. Statement, if you withdraw from the study at any point your data will be immediately and permanently deleted.

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 will be offered 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). By participating in this study, you will be offered 2% extra credit to be put towards the final grade of your selected course. If you choose to forego the in-course credit or are not eligible (i.e., not enrolled in classes where it is offered), you will be remunerated with a $20 Tim Hortons gift card. Should the parking gates at Ontario Tech University require payment during the day(s) of your participation, you will be provided with a parking voucher.

Debriefing and Dissemination of Results:

If you have received this consent form, we are also requiring you fill out the pre-study questionnaire. Question 9 on this form asks "Would you like to be emailed future communications of this research? This includes but is not limited to: conference abstracts, conference presentations, academic publications, and other mediums of scientific communication (NOTE: All dissemination of this data will be group aggregate meaning that no one will be able to deduce your individual results)." Please select yes on this form if you would like this information.

We will also debrief you once you have completed your participation in this study with a thank you letter. The student leads will also answer any questions you have about the study at that time.

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. If you have any questions about your rights as a participant in this study, complaints, or adverse events, please contact the Research Ethics Office at (905) 721-8668 ext. 3693 or at researchethics@ontariotechu.ca.

If you have any questions concerning the research study or experience any discomfort related to the study, please contact the researcher(s) Matt McCue (co-student lead) and/or Sarah Fitzgerald (co-student lead) and/or Nick Wattie (principal investigator) at matthew.mccue@ontariotechu.net and/or Sarah.Fitzgerald2@Ontariotechu.net and/or Nick.Wattie@ontariotechu.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.

Inclusion and participation in this study requires your consent to release gaze behaviour, biomechanical and dart throwing data. All participants need to have 20/20 or corrected to 20/20 vision without the need for prescription glasses. All personal identifiers will be removed from our dataset and no individual data will be presented in graduate thesis, peer-reviewed publications, abstracts, and conference presentations. Individual data will not be shared with anyone and may only be accessed by Matt McCue and Sarah Fitzgerald. By signing this consent form, you agree that your data can be used for the purpose of this study (as described above).

If you agree to participate in this study, we ask that you please complete the pre-study questionnaire and return it with this completed consent form via email to Matt McCue and/or Sarah Fitzgerald.

Consent to Participate:

I agree to participate in this study taking place at Ontario Tech University during the current COVID-19 pandemic. I understand that my participation is optional. I confirm that I have read and understood the consent form and have been advised on the potential risks related to in-person face-to-face research involving human participants at this time.

By checking each of the boxes below, I acknowledge and agree with the statements as follows:

- I have either been fully vaccinated with an approved government vaccine, or I have chosen not to be vaccinated.
- I acknowledge and accept that there is a risk that I could be exposed to COVID-19 while participating in this research project, despite the approved precautions and protocols that have been put in place.
- I acknowledge and accept that while participating in the study, the researchers may need to be closer than the recommended social distancing guidelines in order to carry out the experimental protocols and/or procedures.
- I acknowledge and confirm that I am willing to accept this risk as a condition of attending the university to participate in research.
- I acknowledge and understand that there may be unknown risk related to COVID-19.

- I confirm that the study team has answered all my questions about the study and has advised me of all the risks related to in-person face-to-face research for this study.
- I acknowledge that participating in this study may involve third party risks to others where I may expose individuals that I live with or am in close contact with.
- I have read the consent form and understand the study being described;
- 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;
- 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.

I ____, consent to participate in the *Comparing the effects of different cognitive tasks on dart throwing accuracy* research project conducted by Matt McCue and Sarah Fitzgerald. I have understood the nature of this project and wish to participate. 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. 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. I am not waiving any of my legal rights by signing this form. My signature below indicates my consent for this project and the use of my data for secondary research purposes.

Print Study Participant's name ________________________

Date (YYYY-MM-DD) ________________________

Signature ________________________

****** THIS PORTION ONLY FOR RESEARCHERS ******

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

Signature ________________________

Print Name of Person Obtaining ________________________

Date (YYYY-MM-DD) ________________________

Appendix E

Incongruent Stroop Task Grading Sheet

46 words per sheet, 6 sheets = 276 words total. Have to say the colour they see, **READ text printed when the word is in RED ink. (bolded below)**. Go as fast as possible without making errors. Count errors and words completed (even if they are in the middle of a sheet). Read the left column first then the right column on each sheet.

Sheet 1	**Sheet 2**	**Sheet 3**	**Sheet 4**	**Sheet 5**	**Sheet 6**
Green	Orange	Orange	Green	Orange	Green
Blue	Blue	Grey	Green	Gray	Blue
Yellow	Green	Green	Black	Green	Yellow
Green	Green	**Gray**	**Pink**	**Gray**	Black
Blue	Black	Green	Orange	Pink	Yellow
Black	**Pink**	Black	Yellow	Black	Black
Orange	Orange	Green	**Pink**	Gray	Orange
Orange	Yellow	**Brown**	Gray	Green	**Orange**
Blue	**Pink**	Orange	Yellow	**Brown**	Blue
Green	Gray	Gray	**Black**	Orange	Green
Blue	Yellow	Pink	Blue	Blue	Blue
Pink	**Black**	Blue	Blue	Blue	Blue
Black	Blue	Blue	Gray	**Pink**	**Green**
Gray	Blue	**Pink**	Green	Black	Black

Yellow	**Orange**	Black	Orange	Orange	Green
Blue	Gray	Green	**Red**	Blue	Green
Blue	Pink	Yellow	Orange	Pink	Black
Green	Orange	Orange	Blue	Pink	Yellow
Black	Gray	Pink	Blue	**Blue**	Green
Green	Pink	Blue	Pink	Pink	Black
Black	Black	Pink	Black	Orange	Pink
Yellow	Pink	Pink	Pink	Black	Pink
Pink	Black	Black	Yellow	Orange	**Blue**
Green	Gray	Black	Gray	Black	Pink
Yellow	Yellow	Yellow	Yellow	Yellow	Orange
Orange	Black	Orange	Black	Orange	Black
Pink	Green	Black	Green	Black	**Blue**
Orange	Pink	**Yellow**	Pink	**Yellow**	Yellow
Black	Blue	Green	Blue	Green	Green
Blue	Blue	Pink	**Brown**	Pink	Black
Yellow	Blue	Blue	Green	Blue	**Green**
Green	Pink	Pink	Yellow	Yellow	Blue
Black	Black	Green	Blue	**Green**	Gray

Green	Green	Yellow	**Brown**	Orange	Gray
Blue	Orange	Black	Gray	Pink	Pink
Gray	**Red**	Yellow	Black	Green	Black
Blue	Green	**Orange**	Orange	**Orange**	Orange
Pink	**Brown**	Pink	Pink	Pink	**Pink**
Blue	**Brown**	Black	Gray	Black	Blue
Yellow	Gray	**Blue**	**Orange**	**Blue**	Orange
Pink	Black	Green	Pink	Yellow	Pink
Black	Orange	**Green**	Blue	Green	Black
Orange	Pink	Blue	Gray	**Green**	Green
Pink	Gray	**Green**	Pink	Blue	Blue
Blue	Orange	Blue	Black	Yellow	Green
Orange	**Orange**	Yellow	Yellow	**Blue**	**Orange**

Appendix F

NASA - Task Load Index

Figure 8.6

NASA Task Load Index

Assessment 1

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Failure — Perfect

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix G

Intrinsic Motivation Inventory

Dart Task 1

Motivation

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 dart task 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 H

Task Self Efficacy

How confident are you in your ability to throw the darts more accurately than last time?

0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Not confident										**Totally confident**

Appendix I

Mental Fatigue Visual Analog Scale

Pre (0min) 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

2min-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

4min-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

6min-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

8min--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

10min--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

Appendix J

Brief Trail Self Control

Please answer the following items as they apply to you. There are no right or wrong answers. Please choose a number (1 – 5) that best represents what you believe to be true about yourself for each question. Use the following scale to refer to how much each question is true about you.

	Not at all like me		**Sometimes like me**		**Very much like me**
I have a hard time breaking bad habits	**1**	**2**	**3**	**4**	**5**
I am lazy	**1**	**2**	**3**	**4**	**5**
I say inappropriate things	**1**	**2**	**3**	**4**	**5**
I do certain things that are bad for me, if they are fun	**1**	**2**	**3**	**4**	**5**
I refuse things that are bad for me	**1**	**2**	**3**	**4**	**5**
I wish I had more self-discipline	**1**	**2**	**3**	**4**	**5**
People would say that I have iron (strong) self-discipline	**1**	**2**	**3**	**4**	**5**
Pleasure and fun sometimes keep me from getting work done	**1**	**2**	**3**	**4**	**5**
I have trouble concentrating	**1**	**2**	**3**	**4**	**5**

I am able to work effectively toward long-term goals	**1**	**2**	**3**	**4**	**5**
Sometimes I can't stop myself from doing something, even if I know it's wrong	**1**	**2**	**3**	**4**	**5**
I often act without thinking through all the alternatives	**1**	**2**	**3**	**4**	**5**
I am good at resisting temptation	**1**	**2**	**3**	**4**	**5**

Appendix K

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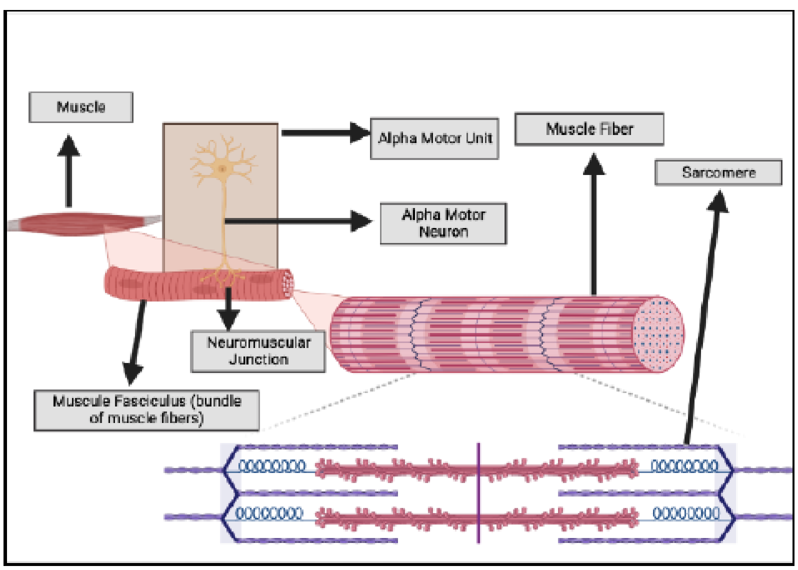

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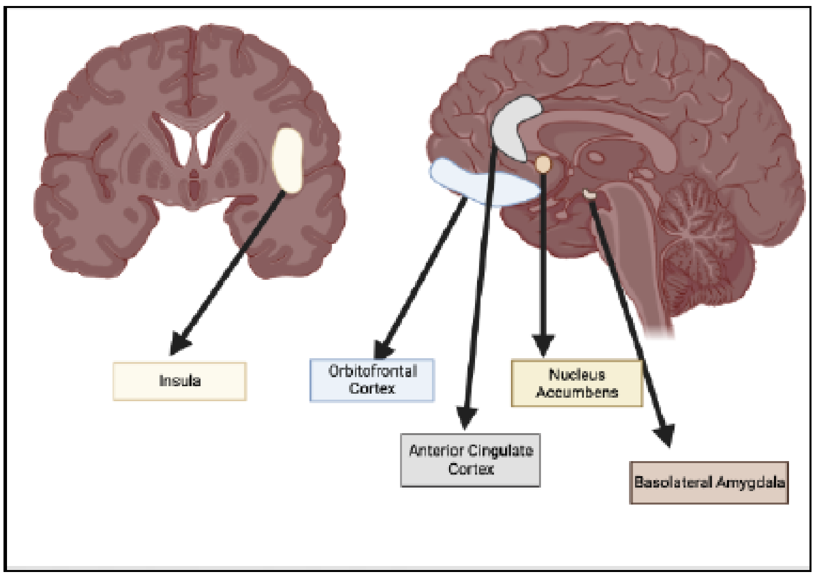

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