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THE IMPACT OF REMOTE AND LOCALIZED KNEE PAIN ON MAXIMAL STRENGTH, FATIGUE PARAMETERS, AND FORCE RECOVERY IN THE KNEE EXTENSOR MUSCLES OF RECREATIONALLY ACTIVE COLLEGE AGED INDIVIDUALS

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THE IMPACT OF REMOTE AND LOCALIZED KNEE PAIN ON MAXIMAL STRENGTH, FATIGUE PARAMETERS, AND FORCE RECOVERY IN THE KNEE EXTENSOR MUSCLES OF RECREATIONALLY ACTIVE COLLEGE AGED INDIVIDUALS

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ABSTRACT

Pain is a widely experienced sensation that has been shown in previous research to decrease duration of exercise and maximal strength. **PURPOSE:** The purpose of this study was to determine if the application of knee pain impacts time-to-task failure and maximal strength measures. It also aimed to see if changing the location of knee pain between the ipsilateral (dominant) leg and the contralateral (non-dominant) impacted fatigue parameters, maximal strength differently and force recovery. **METHODS:** Participants (Females = 9, Males = 12, N/A = 1) completed five visits (2 familiarization and 3 experimental) separated by 48 hours. At the beginning of each of the visits, the electrical stimulus for participants to reach pain threshold and pain rated a 4/10 in the knee was obtained. The exercise protocol consisted of four pre-exercise MVCs (Maximal Voluntary Contractions), submaximal time-to-task failure protocol (intensity of 15% over critical torque), and 6-post exercise MVCs with the different conditions being contralateral knee pain, ipsilateral knee pain or no knee pain. **RESULTS:** The male participants had a higher MVC and twitch torque than the female participants ($p<0.001$) indicating males were stronger than women. Pre-exercise MVCs decreased significantly following application of knee pain, likely due to an increase in central fatigue ($p<0.001$). There was a main effect of time in force decrease ($p<0.001$), twitch torque ($p<0.001$), and % activation ($p=0.005$) during submaximal protocol. Regardless of pain condition, force output was fully recovered 240 seconds after exercise failure ($p=0.067$). Subjective pain measures of exercising muscle pain, regardless of condition, were increased at 60 seconds ($p=0.030$), immediately before failure ($p=0.004$), and immediately following exercise ($p=0.007$). When pain was applied to the ipsilateral knee, pain ratings decreased significantly over time, likely due to exercise induced hypoalgesia ($p<0.001$). Pain ratings in the ipsilateral knee were greater in the ipsilateral

condition than they were in the control condition or the contralateral knee pain condition ($p<0.001$). When pain was applied to the contralateral knee, pain ratings were different over time also likely due to exercise induced hypoalgesia ($p<0.001$). Pain ratings in the contralateral knee were greater in the contralateral condition than they were in the control condition or the ipsilateral knee pain condition ($p<0.001$). **CONCLUSIONS:** The presence of knee pain regardless of location decreased MVCs and increased percent activation of the participants. Knee pain stimulus regardless of location did not impact time-to-task failure. Peripheral fatigue increased throughout the fatiguing exercise protocol. Maximal strength was recovered 240s after fatiguing exercise regardless of the presence and location of knee pain.

Chapter 1

Introduction

Pain is a sensation often experienced on a daily basis. It could be muscle pain following intense resistance training exercise, chronic pain experienced by retired athletes or a clinical disease population, or even the pain of a skinned knee caused by a child falling over on their bike. Pain, especially chronic pain such as arthritis, has been known to hinder activities of daily living and quality of life (Altman et al., 1986), but the impact of pain during an activity has on exercise performance is not fully understood.

When discussing pain and exercise, there are important physiobiological mechanisms to understand. Pain is often defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage (Raja, 2020). Pain is a perception generated by the central nervous system (primarily the brain) in response to the activation of specialized receptors called "nociceptors" that located throughout the body (Stacey, 1969). Pain during exercise is often localized to skeletal muscle. Within skeletal muscle there are various types of nociceptive fibers, each of which responds to distinct stimuli. For example, type III afferent fibers respond to mechanical pressure and deformation and result in a dull pain sensation whereas type IV afferent fibers may respond to biochemical and thermal stimuli and may result in burning pain (Stacey, 1969 and Mense, 1993). Once nociceptors are activated in the periphery, they then transmit a signal to the spinal cord, and then to the brain. Nociceptive inputs are "processed" primarily by the thalamus and then the somatosensory cortex where the "painful" perception is generated (Millan, 1999). Signals are also sent to other areas of the brain such as the amygdala and periaqueductal grey (PAG) leading to pain being a multifactored sensation that is composed of both cognitive and emotional components (Millan, 1999). Muscle pain during exercise likely

results from the accumulation of metabolic byproducts such as hydrogen ions and adenosine as well as increases in intramuscular pressure from force generation and fluid shifts (O'Connor and Cook, 1999). Muscle pain during exercise tends to increase as exercise intensity increases (Cook et al. 1997) and has been suggested to contribute to the development of central fatigue (Mauger, 2013).

Exercise related fatigue is generally accepted as the point at which a participant is no longer able to maintain an expected or desired force output. There are two types of fatigue that contribute to decreased force production. The first type is termed peripheral fatigue and is defined by changes in the ability of a muscle to generate force that occur distal to the neuromuscular junction (Gandevia, 2001). Changes distal of the neuromuscular junction are often the result of hydrogen buildup in the muscle, which can lead to a decrease in the amount of calcium released from the sarcoplasmic reticulum as well as impairment of actin and myosin interactions (Gandevia, 2001). On the other hand, central fatigue is a reduction in force production that occurs due to a change/impairment in the brain or spinal cord (primarily at the level of the alpha motor neuron) that leads to a decrease in the recruitment of motor units. (Gandevia, 2001). There is also evidence of an interaction between peripheral and central fatigue whereby increased type III and IV afferent signals from peripheral fatigue may feedback to the central nervous system and result in reduced motor-unit recruitment and therefore increased central fatigue (Amann, 2008).

Pain during exercise has been suggested to be one of "signals" that may play a role in this interaction between peripheral and central fatigue (Norbury, 2022). Several studies have examined the connection between muscle pain during exercise and the development of fatigue. Several studies (Norbury, 2022; Graven-Nielsen, 1997; Khan, 2011) have found that induction of

muscle pain by the injection of a hypertonic saline solution into the belly of a muscle lowers the maximal strength of that muscle and is accompanied by reductions in motor-unit recruitment and changes in corticospinal excitability. Beyond its impact on maximal strength, other studies have attempted to look at the impact of pain induction on exercise performance. Norbury and colleagues (2021) examined the impact that painful hypertonic saline injection into the muscle belly of the vastus lateralis had on a time-to-task failure test. They found that in comparison to the control (isotonic saline injection), there was a 16% shorter TTF meaning that the hypertonic saline injection resulted in cease of exercise more quickly than the control group (Norbury et al., 2021). They also found that the voluntary force production was lower in the painful condition compared to the control condition after 1 minute and after two minutes of exercise, meaning that the painful condition resulted in decreased voluntary force output (Norbury et al., 2021). In a subsequent study with different participants, Norbury and colleagues looked at the impact of hypertonic saline injection in a muscle of the contralateral limb. They again found that there was a decrease in TTF of 9% in the painful condition, but that there was no impact on measures of central fatigue (Norbury et al., 2022). In a 2020 study conducted by Smith and colleagues, they determined that exercising at 20% MVC (holding 20% of MVC for as long as possible) with the painful hypertonic saline injection resulted in a decrease in TTF meaning that fatigue occurred faster with the pain stimulus.

While the evidence from these recent studies is compelling, there are important limitations with the previous methodologies used to induce pain. The injection of hypertonic saline produces a reproduceable pain that mimics clinical muscle pain, it only lasts four to six minutes and pain tends to progressively decrease over time. This limits the length of time a person can exercise under a given magnitude of pain. As such any exercise test lasting longer

than 5 or 6 minutes would likely not produce valid results. In order to understand the effect of pain on fatigue during longer exercise bouts Gallina et al. (2021) created a pain induction protocol where electrodes attached to the knee to stimulate the infrapatellar fat pad which is higher innervated by nociceptors. The pain from this protocol is like that of osteoarthritis knee pain, and because it is attached to a stimulator can be maintained at a constant level for longer periods of time. Another potential limitation that the use of electrical stimulation of the fat pad addresses is the ecological validity of the pain stimulus and exercise modality. Many of the recent studies have used hypertonic saline injections to induce pain in the muscle which imitates exercise induced muscle pain. This stimulus is painful; however, it is not necessarily representative of pain experienced in day-to-day activities by those with a common clinical pain condition such as arthritis. The electrical stimulation of the infrapatellar fat pad has been shown to mimic the pain described by those with osteoarthritis (Gallina et al., 2021). Therefore, it may represent a pain stimulus with greater ecological validity and therefore greater generalizability as to the effects of knee pain on exercise and physical activity performance in the general population. A study that has used the protocol developed by Gallina et al., in 2021 was published recently this year. Cabral et al., (2023) used electrodes to stimulate the infrapatellar fat pad of the exercising knee in different pain conditions. It was found that both painful conditions decreased knee extension torque. The present study aims to use the same pain stimulus methodology while also taking it a step further and looking at other variables such as pain location and time-to-task failure.

Purpose of the Study

The purpose of the study was to determine if a painful electrical stimulus applied to the knee joint altered maximal strength and endurance exercise performance assessed via a time-to-

task failure test in recreationally active, but untrained, college-aged individuals. Measures of motor-unit recruitment, muscle activation (via EMG), and peripheral neuromuscular function were measured during assessment of maximal strength and during the TTF test to determine the impact of knee pain on these parameters of fatigue. Additionally, since pain induction in both the ipsilateral (Norbury, 2021; Smith, 2020) and contralateral (Norbury, 2022) limb have been shown to induce greater fatigue, a secondary purpose of this study was to determine the effects of the location of pain knee stimulation on exercise performance as well.

Research Questions

The following questions were answered following data collection in this study.

1. Does moderate intensity knee pain, applied to the contralateral or ipsilateral knee alter time-to-task failure compared to exercise without applied knee pain?
2. Does moderate intensity knee pain, applied to the contralateral or ipsilateral knee alter maximal knee extensor strength (e.g., MVC)?
3. Does moderate intensity knee pain, applied to the contralateral or ipsilateral knee alter parameters of central and/or peripheral fatigue during exercise compared to exercise without knee pain?

Research Hypotheses

H_1 – Knee pain will result in a greater increase in muscle pain than no pain.

H_2 – Knee pain will decrease time-to-task failure (TTF).

H_3 – Knee pain will decrease maximal force output (MVC).

H_4 – Knee pain will decrease twitch force (TF).

H_5 – Knee pain will increase voluntary activation (%VA) during fatiguing exercise.

H_6 – Knee pain will decrease force recovery following fatiguing exercise.

H_7 – Knee pain will cause %VA to return to baseline levels slower than no pain.

H_8 – Knee pain will cause TF to return to baseline levels slower than no pain.

Significance of the Study

Knee pain is a significant problem for athletes in addition to the general population. Aside from lower back pain, knee osteoarthritis and associated joint pain are among the most common clinical pain conditions (Michael et al., 2010). Retired athletes and recreationally active individuals also develop osteoarthritic knee pain at younger ages due to increased use and overload. For example, it was found that in retired NFL players under the age of sixty, arthritis is over three times more common than in the general population (Golightly et al., 2009). A 2001 study of retired professional soccer found that of the 185 respondents, 47% retired due to injury. Of those athletes, 58% also reported painful, chronic injuries. Furthermore, 46% of chronic injuries that led to retirement were of the knee. The questionnaire found that 32% of the athletes that retired due to chronic injury were diagnosed with osteoarthritis of at least one of the lower limb joints (Drawer et al., 2001).

Laboratory based models to assess the impact of pain on exercise are limited, especially forms of pain that are representative of pain experienced by large populations on a regular basis. Other forms of pain such as exercise induced muscle pain can be replicated by means like the hypertonic saline injection, but they are not long lasting as the pain would be in clinical populations. Pain can also be administered in the form of temperature or pressure, but it again would not be representative of pain that is likely to impact exercise.

Testing of osteoarthritic populations cannot be done because of the likelihood that the symptoms could be exacerbated. This mechanism of inducing pain similar to that experienced by osteoarthritic populations allows for the impact on exercise performance to be studied without placing participants in harm's way.

Delimitations

1. Participants are male and female.
2. Participants are recreationally trained.
3. Participants are not currently taking pain medications, prescribed by a provider or over the counter.
4. Participants do not have any preexisting knee or leg injuries.
5. Female participants are not pregnant and have regular menstrual cycle.
6. Participants are not currently prescribed and taking psychological medications.
7. Exercise completed will be intermittent submaximal isometric contractions.

Limitations

1. Only recreationally active individuals are included.
2. Only college aged individuals.
3. Knee pain will be administered only through electrical stimulation of the infrapatellar fat pad.

Assumptions

1. Participants will give their full effort in the MVC exercise.
2. Participants will be honest about their pain levels.
3. Participants will reach true failure during the fatigue protocol.
4. Interpolated twitch technique accurately estimates median frequency.

Operational Definitions

1. Pain Threshold – The minimum stimulus that is no longer perceived as a sensation, but is perceived as painful or tender (Hardy et al., 1943)
2. Pain Tolerance – the maximum amount of pain that an individual is able to tolerate (O'Connor and Cook., 1999).
3. Pain Intensity – Subjective pain measure on a scale of 0-10 used to indicate how painful a stimulus is (zero being no pain, ten being unbearable or unimaginable pain) (Jensen et al., 1986).
4. MVC – Maximum voluntary contraction. A maximal contraction that a subject accepts as maximal that is produced with appropriate continuous feedback of achievement (Gandevia, 2001).
5. EMG – Electromyography. Measure of electrical activity of working muscles that provides easy access to physiological processes causing force generation, fatigue, and function (Kollmitzer et al., 1999).
6. RMS – Root Mean Square. The average absolute value of the amplitude of the electrical activity produced by exercising muscles (Kollmitzer et al., 1999). Proven to be the most sensible and reliable.

7. Twitch– An electrical signal given to the muscle to elicit an involuntary contraction that can be used as a measure of peripheral fatigue (Gandevia, 2001).
8. ITT – Interpolated twitch technique – A measure of voluntary muscle activation where a stimulus is delivered to motor units that are previously engaged in a voluntary contraction (Gandevia, 2001).
9. TTF – Time-to-task failure. The amount of time that a participant is able to generate a prescribed amount of force before they are physically unable to continue at the same intensity (Gandevia, 2001).
10. Central fatigue – A continuous reduction in voluntary activation of muscle during exercise (Gandevia, 2001).
11. Peripheral fatigue – Fatigue that is due to changes distal to the neuromuscular junction. (Gandevia, 2001).
12. Motor unit recruitment – The process of increasing the number of active motor units during a contraction to increase the amount of force produced by a muscle (Adrian and Bronk, 1929).
13. Ipsilateral – belong to or occurring on the same side of the body.
14. Contralateral – Belonging to or occurring on the opposite side of the body where a condition occurs.

Chapter 2

Introduction

Because pain is so widely experienced in everyday life as well as in sports, it is important to understand the mechanisms behind it, as well as how it has been studied in the past. In the present study, we are attempting to determine if remote and localized pain stimulus in the knee joint impacts the neuromuscular function of the knee extensors of the dominant leg. For the purpose of gathering background information on pain and exercise, a series of searches were conducted. All searches occurred on OU libraries using CINHAIL complete, MEDLINE, PubMed, SportsDiscus, Web of Science, and Google Scholar. Additionally, many articles pertaining information related to the topics were provided by Dr. Black.

The initial search was intended to gain information on the physiology of pain and afferent signaling. Keywords of this study were "pain, threshold, tolerance, afferent, nociception, CNS and PNS. Studies and chapters were included if they discuss the mechanisms of pain signaling. Studies were excluded if they did not discuss how the nervous system conducts pain stimulus.

The second search was used to determine the difference between pain tolerance and threshold as well as the types of pain stimuli. Key words in this search were pain tolerance, pain threshold, and pain stimuli. When talking about different pain stimulus, articles were included if they mentioned the ways that pain can be induced as well as if both tolerance and threshold measurements can be obtained. The information gathered was used to determine the most ethical mechanisms to induce pain and to understand the differences between the mechanisms. Additionally, the articles found in this search

provided information on the definitions and measurements that will be taken throughout the duration of this study.

The third search was concerning how several types of exercises impact the pain tolerance and threshold measures. The current study will also be looking at how pain can impact exercise performances themselves. Key words and phrases for this search included aerobic training and pain, resistance training and pain, isometric training and pain, pain threshold, and pain tolerance. Studies were included if they determined that exercise did impact pain tolerance and threshold measures in some manner. Additionally, each article selected for review examined a different pain stimulus.

The fourth section of chapter two discusses the impact that pain has on exercise performance. It examines the effect that different pain stimuli have on performance, as well as how pain impacts neuromuscular function during exercise.

The final section of this chapter was on the different pieces of equipment that will be used. Information was obtained on the Kincom dynamometer, EMG, direct muscle stimulation, as well as the validity of the pain scale measurements, pain catastrophizing scale (PCS), PAR-Q+, profile of mood states (POMS), international physical activity questionnaire (IPAQ), pain attitude questionnaire (PAQ).

The Physiology of Afferent Signaling

The body communicates in an abundance of ways, one of the most common being electrical signals that are propagated down nerves. These signals can travel in two directions. Efferent signals are those that travel from the central nervous system to the periphery. These are typically motor neurons that signal the muscles to contract. There

are also afferent signals that are sensory information traveling from the periphery to the central nervous system. Pain is an example of an afferent signal that is transmitted to the brain. Nociceptors are found at the earliest stages of pain perception in the body, as they are the ends of sensory neurons (Reichling et al., 1999). Additionally, Reichling et al. (1999) discusses that there are different types of nociceptors including mechanical, chemical, and thermal. Each of these nociceptors is sensitive to a specific stimulus and when the stimulus is detected, it transmits a signal to the brain via afferent fibers (Black, 2012). As the pain stimulus increases, signals are transmitted to the central nervous system at a higher rate. The more intense the stimulus is, the more painful it is perceived.

Pain Threshold and Tolerance

When discussing pain, it is important to understand how the perception of pain changes with the stimulus. When stimuli become progressively stronger over time, it reaches a point that is termed the pain threshold (Black, 2012). The pain threshold is the point when the main stimulus changes from being a sensation to being a painful stimulus. It is essentially the point where it transitions from a normal feeling to a painful feeling. There is also pain tolerance. The pain tolerance of an individual is the greatest amount of time an individual is willing to endure a pain stimulus, or the greatest stimulus a person willingly endures (O'Conner et al., 1999). Pain threshold is an easier measure to obtain because subjects are not exposed to extreme pain. In some situations, it may be unethical to assess pain tolerance. For example, when looking at heat stimuli, only thresholds can be assessed because exposing a subject to heat levels near their pain tolerance would lead to tissue damage which is unethical.

Types of Pain Stimulus

Mechanical pain stimuli can be induced using a few different pieces of equipment. The most common device used is a handheld algometer (Melia et al., 2014). According to Melia et al. (2014) one of the drawbacks is that it is difficult to maintain reliability over multiple testing periods. In addition to handheld algometers, there are fully automatic pressure algometers that can be adjusted to test pain perception in twenty-nine different locations (Melia et al., 2014). It was found in this study that the electromechanically driven algometer increases the accuracy of mechanical pain measurements. The present study will be using electrical stimulation of the non-exercising knee joint as a remote pain stimulus.

A second type of pain stimulus that is used often is electrical stimulus. The most common type of electrical stimulus is transcutaneous electrical nerve stimulation (TENS). TENS units have been used as a pain relief practice because when electrical stimuli are placed on the muscle, afferent signals travel to the CNS on the same pathways that pain travel meaning that TENS reduces sensitivity to pain (Vance et al., 2014). Electrical stimulation at higher intensities can serve as a pain stimulus during research. A study conducted by Nakashima et al. (2014) used electrical stimulation on the roof of the mouth to stimulate every sensory nerve with the intent of calculating the oral pain tolerance threshold of subjects. Gallina et al. (2021) used electrical pain stimulus to stimulate the infrapatellar fat pad of the knee in order to induce musculoskeletal pain in the leg. The positioning of the electrodes allows pain to be presented to the knee while also allowing the remainder of the leg to be available for other measurements such as EMG to

understand individual response to the pain. Gallina and colleagues found that this model can be used to examine the relationship between movement and pain.

The final two types of stimuli that can be used to calculate pain measurements are thermal stimuli. Both hot and cold stimulus can be used. Heat stimulus, as stated before, is only used to obtain pain threshold measurements. A common device used to induce heat stimuli is the Peltier thermode (Yarnitsky et al., 1994). This device can also be used to produce cold stimulus. A less expensive way to expose the body to a cold stimulus is with a bucket of ice water. A study conducted by Birklein et al. (2007) used a cold pressor test to determine if cold pain tolerance was genetic. The subjects placed their hands in cold water that was 1 degree Celsius and held it there as long as they could. Pain tolerance was reached when the subjects removed their hand from the cold stimulus.

Because there are so many mechanisms to measure both pain tolerance and pain threshold, it is important to consider which stimulus is best suited for each individual study. For this study, electrical stimulus will be used because it is possible to exercise with electrodes attached to the body. It would be nearly impossible to assess mechanical pain perception and would be exceedingly difficult to test thermal pain perception while exercising.

Exercise type and Pain Perception

Many studies have examined different types of exercise to determine if it impacts pain tolerance or threshold. Jones et al., (2014) studied the impact that moderate to vigorous aerobic exercise has on pain sensitivity in adults. Participants in this study completed 30 minutes of exercise on a cycle ergometer at 75% of their heart rate reserve

(HRR) three times per week. Following 6 weeks of aerobic training, they found that the aerobic exercise increased pain tolerance to noxious ischemic stimuli, but that pressure pain thresholds and RPE were unchanged. Micalos et al. (2016) also studied the impact that aerobic exercise has on pain perception. Pre/post measurements were taken of mechanical pain tolerance at rest, as well as at 30% and 70% of VO2max. The results of this study found that aerobic exercise decreases pressure pain sensitivity in remote locations at 30% of VO2max. Both studies were in agreement that aerobic exercise increase pain tolerance and threshold measurements following cessation of exercise.

In addition to aerobic training, studies have examined the impact that resistance training has on pain perception. Koltyn et al. (1998) measured the pain perception of thirteen subjects following 45 minutes of rest and 45 minutes of resistance exercise at 75% of their 1RM for a series of exercises. The study found that pain threshold was higher, and ratings of pain were lower 5 minutes after exercise. In a review article by Ellingston et al. (2019) it was determined that resistance training decreased levels of pain perception, but also that isometric exercise has been shown to increase pain tolerance and threshold levels

Isometric exercise is the third type of training that has been studied in relation to pain tolerance and threshold. Vaegter et al. (2017) compared pressure pain tolerance and heat pain tolerance before and after isometric exercise as well as before and after quiet rest. The study found that pressure pain tolerance was increased after exercise when compared to rest. Additionally, it found that heat pain threshold and pressure pain threshold were not increased by exercise.

The present study will use intermittent isometric contractions to induce fatigue in the participants. Although isometric contractions are not common in athletics or even in

daily life, they are much more controlled and easier to accurately measure. Because of this, there is less error and more consistency in measurements. Instead of using a constant isometric contraction, an intermittent contraction will be used to make it as realistic and generalizable as possible.

The Impact of Pain on Exercise Performance

Pain has been shown to decrease exercise performance and increase rates of fatigue. A number of authors have utilized hypertonic saline injections in order to induce experimental muscle pain to determine the impact that pain has on exercise capacity and fatigue. Norbury and colleagues conducted two studies to determine the effect of increased muscle pain on fatigue. Norbury used an injection of hypertonic saline into the muscle belly of the vastus lateralis. In the first study published in 2021, they determined that hypertonic saline injections decreased TTF, and decreased maximum force output meaning that the painful stimulus caused the participants fatigue faster and were not able to generate the same amount of force as the control condition (Norbury., 2021). In a second study published in 2022, Norbury and colleagues used different participants and the same protocol in the contralateral leg to examine the effects of a painful hypertonic saline injection on fatigue and performance. With the injection in the contralateral leg, they found that there was a reduction in TTF, but that the force output did not change between conditions (Norbury et al., 2022). This meant that while the force output was the same, the participants fatigued at a faster rate during the hypertonic saline injection. The limitation in Norbury's study is that they did not use the same participants. The proposed study will

use the same participants for the contralateral, ipsilateral, and control conditions so that each individual is their own comparison.

Smith and colleagues also used hypertonic saline injections to determine the impact that pain has on fatigue and exercise performance. In a 2020 study, Smith et al. injected hypertonic saline into the vastus lateralis of the participants in order to determine if muscle pain impacts fatigue and TTF. They found that the hypertonic saline injection elicited similar pain intensities to exercise induced pain and that the hypertonic saline injection resulted in shorter TTF meaning that the pain limited exercise performance (Smith et al., 2020). In a second study published in 2020, Smith et al., injected hypertonic saline and instructed participants to reproduce force output in an attempt to determine if pain similar to exercise induced pain (EIP) impacts the ability of participants to accurately reproduce torque. They found that with the hypertonic saline injection, participants were not able to accurately reproduce knee extensor torque and that it indicates that exercise induced muscle pain impacts exercise regulation and performance (Smith et al., 2020).

In a review article, Mauger outlines the relationship between pain and fatigue. Previously, fatigue was thought to be strictly peripheral, meaning that it occurs distal to the neuromuscular junction. However further research and publications have brought to light the relationship between central fatigue, peripheral fatigue, pain, and task failure. As Mauger mentions in his article, pain is defined as an unpleasant emotional or physical experience with the potential to damage the body, indicating that it is subjective with an emotional element (Mauger, 2013). This indicates a strong central component, especially when exercise ceases prior to true fatigue. Mauger is also sure to point out that previous studies have had conflicting results when determining the impact pain has on exercise

performance. Some studies such as one published by Khan et al. (2011) has results similar to Norbury and Smith and found that a hypertonic saline injection reduced maximal voluntary torque (MVT). Two studies conducted by Ray and Carter (2007) and Hudson et al. (2008) found that pain management medication did not affect exercise performance at a fixed intensity. However, Mauger et al. (2010) discovered that acetaminophen significantly improved self-paced exercise performance (Mauger, 2013). It is possible that the difference in results is due to the form of exercise but could also be due to differences in individual responses or testing mechanisms.

Duration of Pain Stimulus

When designing pain studies, it is important to determine when the pain stimulus is being implemented. Studies conducted by Jones et al., (2014), Micalos et al. (2016), Koltyn et al. (1998), and Vaegter et al. (2017) are examples where the perception of different pain stimuli were recorded before and after a control or intervention. The present study will follow a different experimental design that combines previous fatiguing exercise protocols from Norbury et al. (2022) and pain stimulus from Gallina et al. (2021). Norbury and colleagues utilized an injection of hypertonic saline into the muscle immediately before exercise to induce pain however with the pain stimulus only lasting 4-6 minutes, their fatiguing exercise protocol was designed to last the same amount of time as the pain caused by the hypertonic saline. They used an intermittent contraction pattern that is similar to the present study. The downside to the protocol designed by Norbury and colleagues is that the participants did not reach true fatigue. The exercise protocol was designed to be fatiguing, but because the exercise protocol and pain stimulus only

lasted a set amount of time, it is not determined if true fatigue was reached. Gallina et al. placed electrodes over the infrapatellar fat pad of the knee to illicit a pain similar to that of osteoarthritis. The pain stimulus used by Gallina can be continuous throughout the exercise and is more representative of pain experienced by athletes and active individuals every day. It also allows participants to reach true fatigue because the pain stimulus can occur as long as needed. The combination of these protocols will be used in the present study so that the pain stimulus of the knee lasts longer than 4-6 minutes, and so that the exercise is more representative of athletics.

Pain and the Menstrual Cycle

The menstrual cycle occurs in three phases. The first phase is the menstrual phase (days 1-5) where menstruation is actively occurring. During this period of time, all hormone levels are at their lowest. Immediately following menstruation is the follicular phase (days 6-13). During the follicular phase, the majority of the hormones are relatively low, with a surge of estrogen and progesterone occurring around days 12 and 13 leading up to ovulation. Ovulation is the release of the egg from an ovary. It occurs on day 14 of the cycle and separates the follicular and luteal phase. During ovulation, there are extremely high levels of progesterone, estrogen, follicle stimulation hormone (FSH) and luteinizing hormone (LH). The luteal phase occurs after ovulation and is days 15-28 of the cycle. During this phase, LH and FSH decline immediately while progesterone rises until approximately day 22. At days 27 and 28, all hormone levels decrease. If fertilization of an egg has not occurred, menstruation will begin and the cycle will start over at day 1.

Women have been previously understudied due to the difference in hormones during the menstrual cycle. Pain intensity changes throughout the phases of the menstrual cycle. As the hormones fluctuate, pain thresholds and tolerances change along with it. A metanalysis conducted by Riley et al. in 1999 examined the differences in pain perception throughout the menstrual cycle and examined how tolerance and threshold of each pain stimulus differed. They determined that pressure pain threshold, cold presser pain, thermal heat stimulation, and ischemic muscle pain demonstrated higher thresholds during the follicular phase of the menstrual cycle, rather than later phases (Riley et al. 1999). They also determined that the pain threshold for electrical pain stimulus was highest in the luteal phase of the cycle and that tolerance measures from each form of pain stimulus followed the same trends as the threshold measurements.

Objective Measurements

In addition to TTF, additional objective measurements have been used to measure peripheral and central fatigue during exercise. To measure and better understand both types of fatigue, direct muscle stimulation of the knee extensor muscles has been used. A study conducted by Black et al. (2021) used direct muscle stimulation to measure twitch torque. Electrodes were placed on the distal vastus medialis and the proximal vastus lateralis to generate an electrical field that stimulates all knee extensor muscles (Black et al., 2021). The researchers connected the electrodes to force transducer and delivered electrical signals to the knee extensors in a paired 0.2 m pulse with an interpulse interval of 10m beginning at currents of 40 milliamps (mA) (Black et al., 2021). The same muscle stimulation protocol is proposed for the present study. Direct muscle stimulation gives

researchers a measurement for voluntary activation that can be used to measure increased central fatigue following exercise.

Maximal voluntary contractions (MVC) are used to measure the maximum strength that an individual is able to voluntarily generate. It is an objective measurement that has the ability to determine fatigue and force decline over time. MVC contractions require strong verbal encouragement as they are exhausting and difficult to complete. MVC is a commonly used measurement to analyze the strength of participants. In a 2001 study by Rainoldi et al., it was found through the use of surface electromyography (EMG) that voluntary isometric contractions of the knee extensors showed a light level of repeatability. This indicates that the MVC measurement is consistent between days and is an accurate representation of voluntary force production. Because of this, many studies have incorporated the measurement to determine fatigue. Black et al. used MVC measurements in order to determine baseline values for strength (2022). The study conducted by Black and colleagues used MVC measurements from participants in order to prescribe exercise at the same relative intensity to all participants in an attempt to determine if a carbohydrate mouth rinse impacted fatigue at 20% MVC or 80% MVC (Black et al., 2022).

Critical Torque (CT) is the maximum amount of force that can be maintained by an individual without fatigue. This is measured in the knee extensor muscles using maximal intermittent isometric contractions. CT tests are 5 minutes long and can be done using duty cycles of 3s on, 2s off or 6s on, 4s off. The participant will give maximal effort during each contraction and will continue until the test is over. As the contractions continue, they decrease progressively over time due to increases in peripheral fatigue

(Pethick et al., 2016). Eventually, participants force output levels off and the average of the final three contractions is the participants' critical torque. Critical torque can be used to prescribe submaximal exercise. It is common in studies for researchers to prescribe exercise at a certain percentage of MVC. However, this results in individuals fatiguing at different rates due to the variability of critical torque among individuals. Giving participants a percentage of their MVC to work at is not necessarily the best or only way to prescribe submaximal exercise. For example, 60% of an individual's MVC may be significantly over one individuals CT, but only slightly over a second individuals CT. It is not a person's maximal strength that determines their rate of fatigue, but the percentage of which they are working over their critical torque. Therefore, a solution for exercise prescription in this study is to prescribe exercise at 15% above CT. The exercise intensity will still be relative to each individual but will focus on CT instead of MVC. According to data in an unpublished dissertation by Grant Chesbro, it was determined that exercising at 15% above CT resulted in failure being reached at approximately 5.5 minutes.

The final objective measurement that will be used in the present study is surface electromyography (EMG). During exercise, each muscle contraction is generated by an electrical signal received from the nervous system. The electrical activity travels throughout the muscle and is increased as the strength of the contraction increases. EMG measures the electrical activity of the muscle. EMG presents a number of variables that present an increased understanding of fatigue during exercise. In a 2018 study conducted by Hight et al. EMG was used to measure electrical activity from the soleus during maximal voluntary exercise as well as during interpolated twitch technique (Hight et al., 2018). EMG electrodes are placed over the muscle belly of the intended muscle, with a

grounding electrode placed on a bone. Following completion of exercise, EMG root mean square, m-wave, and v-wave peak to peak variables were determined in order to determine rates of fatigue (Hight et al., 2018). These measurements provide insight into voluntary activation, motor unit recruitment, central and peripheral fatigue. The present study will use EMG to obtain the same variables as the study conducted by Hight et al. With EMG being a common measurement in exercise testing, many studies have been done to determine the validity of the measurements and instrumentation. Mathur et al. intended to determine the test-retest reliability of median frequency and amplitude of the quadriceps muscles. They found that across multiple testing days, there were moderate to high reliability for median frequency (ICC = 0.59-0.88) and amplitude (ICC = 0.58-0.99) among all muscle groups (Mathur et al., 2005). This indicates that although measurements may vary slightly due to variables such as electrode placement, size or shape, and hydration status; the measurements are similar between days making it an accurate measure of electrical activity of the knee extensors.

Subjective Measurements and Surveys

There will be subjective measurements taken to see how individuals respond to pain. The subjective measurement that will be taken is a pain perception measure on a scale from 1-10. This measure will refer to the knee pain and will be taken at the beginning of exercise and immediately after failure. The pain should be rated as a 4/10 at the onset of exercise and will be measured again at the end.

A series of surveys will be used to ensure that participants are fit to participate in the study, as well as see how mood and personality impact the pain perception and fatigue

rates. The first study that will be used is the modified profile of mood states (POMS) survey. The POMS survey is used to measure psychological distress of participants. It was originally 65 prompts that were responded to on a Likert scale of 1-5, but a modified version was made called the brief POMS which has thirty-seven of the original items and yields a score for overall psychological distress (Curran et al., 1995). The brief POMS produces comparable scores to the full version and takes a fraction of the time. The POMS survey is necessary because individuals experiencing high levels of stress or depression may perceive pain differently and will in turn skew the results of the present study.

Another survey that will be used is the pain catastrophizing scale (PCS) which is used to measure catastrophic thinking related to pain (Sullivan et al., 1995). This survey is thirteen questions long and asks participants to reflect on a time where they were in pain and to think about how they felt in that moment. The idea is for researchers to get an understanding as to how participants react when they are exposed to pain. Some may not be concerned about it, whereas others may feel pain on a more magnified level. In this study, researchers will be looking to see if there is a correlation between catastrophizing and pain threshold, the pain stimulus rated a 4/10, and the fatigue rates of participants.

A third survey that will be used is the pain attitudes questionnaire (PAQ) which is used to determine how aware participants are of pain and pain stimuli. This survey specifically wants to measure stoicism and cautiousness (Yong et al., 2001). This scale was determined in the study by Yong to be reliable and valid in measuring attitudes towards pain. This study will be used by researchers to determine how participants view pain on a daily basis and how pain typically impacts their actions on a daily basis.

The next survey that will be used is the international physical activity questionnaire (IPAQ). Participants in the study are to be recreationally active, and this allows researchers to ensure that participants are fit to complete the study. The IPAQ has four sections. The first asks participants to list the number of days per week they engaged in vigorous activity and how many hours and minutes they spent doing so. The second section asks participants to list the number of days per week they spent engaging in moderate activity and how long they spent doing so. Sections three and four ask the same of walking and sitting.

The final survey used is the physical activity readiness questionnaire for everyone (PAR-Q+). This survey is used to determine if participants have any underlying conditions that researchers must be aware of or that disqualify them from being able to participate in the study. If participants answer no to every question on page one, then they are healthy and can participate in the study. Pages two and three are utilized if a participant answered yes to any of the questions which indicates an underlying health issue.

Conclusion

At this point in time, there is no study that uses electrical stimulation of the infrapatellar fat pad to induce knee pain while doing isometric knee extension exercise of the dominant leg. Additionally, this study will compare the effects of both remote pain and localized knee pain. The present study will combine measures of pain perception, pain desensitization, muscle recruitment, and resistance to fatigue while experiencing contralateral and ipsilateral knee pain during exercise.

Chapter 3

The purpose of this study was to understand the effects of remote and localized pain on knee extensor muscle function during exercise. We hoped to answer the question, does remote and/or local knee pain impact an individual's maximal strength and exercise capacity judged by TTF.

Sample

A G*Power calculation using an effect size of d=0.8 SD (Cohen's D) (Cohen, J. 2013) (based upon the magnitude of reduction in TTF from Norbury et al., 2022) and a mixed model 2x3 condition (No pain, contralateral knee pain, and ipsilateral knee pain) within measures ANOVA produced a required sample size of 16 total participants to yield a power of 0.80 with an alpha level of $p < 0.05$. There were a total of 22 participants that completed all five of the visits. The sample consisted of 12 men and 9 women. There was one individual that chose not to disclose their sex.

Recruitment took place in a variety of locations around OU's Norman Campus. Recruitment flyers were posted around the Department of Health and Exercise Science and with a mass email sent through the University of Oklahoma's mass email system. Additionally, verbal recruitment took place in the classrooms of instructors within the Health and Exercise Science Department and in similar fields who allowed the researchers time to come and verbally recruit students.

Participants were included if they self-report no history of neuromuscular injuries and can exercise at high intensities. A PAR-Q plus will be given to all participants prior to any exercise to ensure that they have no pre-existing conditions that will put their health at risk. If participants answer "yes" to any of the questions, they must receive physician permission to participate. Individuals that have had previous knee surgeries and preexisting knee injuries within the last 6 months, are not able to withstand high intensity exercise, or are completely sedentary will not be

included in the present study. This study defined "active" if an individual meets the ACSM guidelines for physical activity by self-report and if they are not actively training for an event such as a race or lifting competition. Finally, female participants who self-reported a regular menstrual cycle every 21-35 days (Creinin et al., 2004) and were not pregnant were able to participate. Testing occurred during the luteal phase of the menstrual cycle where levels of estrogen and progesterone were the highest. During this phase, participants had the highest threshold for electrical pain stimulus, and hormonally they were the closest to females who are regularly taking hormonal birth control. Testing women during the luteal phase allowed women who are taking birth control to be included as well. Participants were asked to refrain from exercise 24-hours prior to testing and were asked not to consume caffeine, over the counter pain medications, or other supplements on the day of testing to ensure that pain perception or exercise performance were not impacted by substance consumption. If at any time a participant did not follow the researchers' requests, they were asked to leave and come back a different day without taking supplements or exercising.

The final criteria that participants were required to meet before was that their POMS score was in the negatives, meaning that their vigor score outweighed their other scores. If the score was positive, researchers asked the participant a series of questions and then determined if it was safe for the participant to participate or if it would be dangerous and negatively impact them.

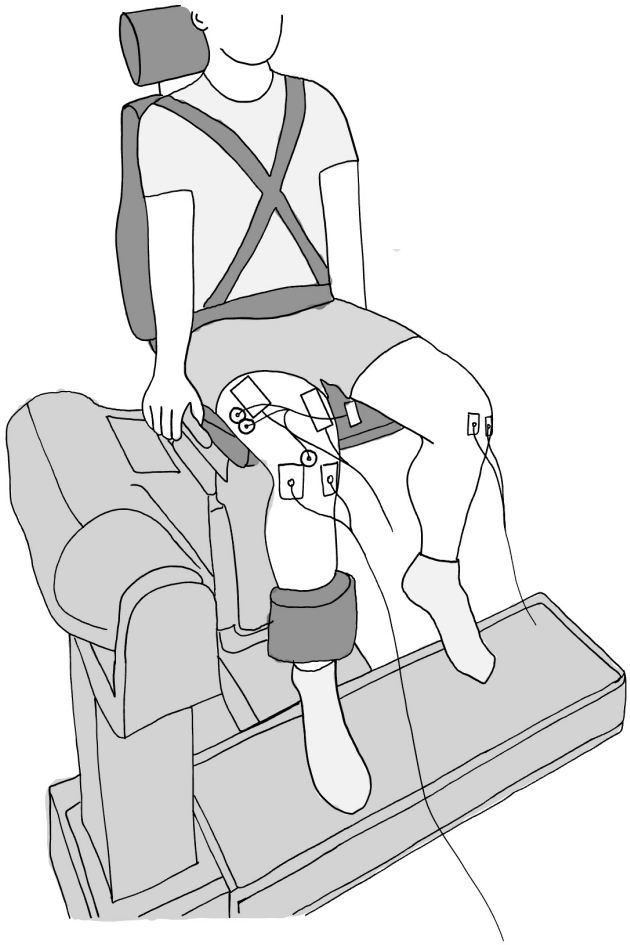

Figure 1 (above) - Participant body position with attached equipment used for data collection. Image adapted from Cabral et al. (2023).

Experimental Design

This study used a repeated measures experimental design where each participant was tested five times over the course of 7-10 days and served as their own control. The first two testing days were for familiarization of the testing procedures and the latter three days were experimental visits with counterbalanced pain conditions.

Visit 1 – Familiarization: Written and verbal explanations of the experiment were given, and all questions from participants were answered prior to the signing of consent forms. Once the

HIPAA form was signed and written consent was obtained, participants completed a series of surveys and questionnaires to ensure participants were fit to complete the study. In addition to ensuring fitness to participate, some of the questionnaires served as tools for secondary analysis to better understand the relationship of performance to questionnaire responses. The forms that were completed include a physical activity readiness questionnaire (PAR-Q+), international physical activity questionnaire (IPAQ), pain attitude questionnaire (PAQ), pain catastrophizing scale (PCS), and profile of mood states (POMS). At this time, they also filled out a menstrual cycle regularity form. Participants were familiarized with a scale that was repeatedly used to rate their pain intensity on a 0-10 scale (Cook, 1998). Following the paperwork, participants height, weight, age, and moment arm were recorded.

Visit one also included familiarization of procedures for testing maximum voluntary contraction (MVC) of the knee extensors, interpolated twitch technique (ITT), time-to-task failure (TTF) at 60% of MVC, and application of the electrical stimulus to the knee to induce knee pain. During the first visit, researchers also recorded the Kincom placement so that prior to participants arriving for future visits, the Kincom will be positioned correctly to save time.

Visit 2 – Familiarization: The second familiarization visit was further familiarization of MVC, ITT, TTF, and the electrical stimulus to induce knee pain. A POMS survey was given at the beginning of this visit with the same purpose of ensuring participant well-being. Following completion of the POMS questionnaire, participants were familiarized with the electrical stimulus and the electrical stimulus at pain threshold and at pain rated a 4/10 was recorded. This was done prior to any exercise familiarization to prevent inaccurate readings due to exercise induced hypoalgesia. Before the MVC, ITT, and TTF familiarization, a Critical Torque (CT) test

was given to determine critical torque as well as prescribed intensity during submaximal fatiguing exercise. Instead of familiarizing participants with a submaximal prescribed exercise of 60% of their MVC, the second visit used 15% over the calculated critical torque for the TTF protocol practice.

Visits 3-5 – Experimental: Visits three, four, and five were identical except for the location of application of the pain stimulus which was randomized and counter-balanced using a random research generator so that all participants experienced three conditions: 1. pain in the ipsilateral (exercising) leg, 2. the contralateral (non-exercising) leg, and 3. a no knee pain condition to serve as a control. When participants arrived, they were given the POMS questionnaire. If their POMS scores were acceptable, they were placed in the KinCom. All electrodes were attached to the participants at that time.

The first measurements obtained were the electrical stimulus required for participants to reach their pain threshold and their pain rated at a 4/10. The next measures to be assessed are MVC with ITT and twitch. Two measures were taken with no pain applied to the knee followed by 2 assessments taken with pain applied for 5-seconds prior to and during the assessment. This allowed for a determination of the effects of knee pain on maximal strength and measures of central and peripheral fatigue. There were two minutes separating each of the maximal contractions.

Following 5 minutes of rest, the time-to-task failure test occurred. Participants performed intermittent isometric contractions (6 second contractions followed by 4 seconds of rest) at a force equal to 15% over their CT. This continued until they can no longer reach the target force for 3 consecutive contractions. During the TTF test, electrically stimulated twitch force was

assessed after every 3rd contraction (approximately every 30-sec), and a MVC with ITT will be performed after every 6th contraction (approximately every minute). Ratings of muscle pain in the right knee, left knee, and exercising muscle were obtained approximately every 30 seconds as well. Once task failure has been reached, a MVC was performed immediately, and then 5 additional MVCs were performed with one minute of rest in between to examine the force recovery of participants 5 minutes to after fatiguing exercise. See below in Figure 1 for a visual of the experimental design.

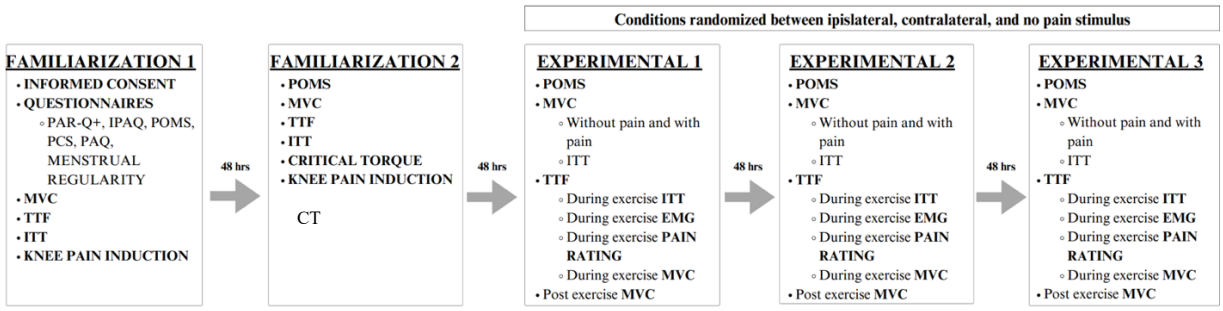

Figure 2 (above) – Experimental Overview of all measures and procedures that will take place across each of the five visits of this study.

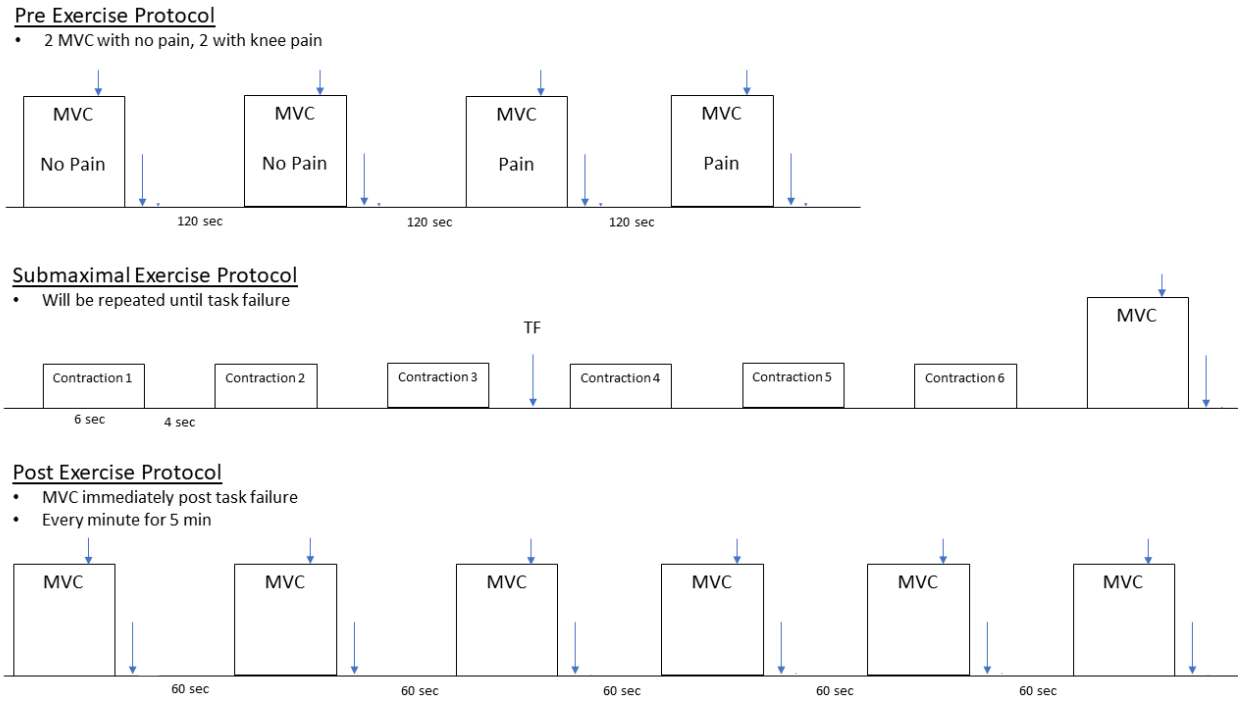

Figure 3 (above)– Overview of contraction sequence for Pre, Exercise, and Post-exercise assessments of MVC, twitch-interpolation, twitch force (blue arrows)

Experimental Procedures

Questionnaires

The profile of mood states (POMS) questionnaire was given at the beginning of each of the five visits prior to any exercise taking place. The purpose of this questionnaire was to determine the mood of the participants prior to exercise and use the results for secondary analysis following the completion of the study. The full POMS questionnaire is a 65 item, 5-point Likert scale with the intention of measuring six different moods. These include tension/anxiety, depressed mood, confusion, anger, fatigue, and vigor. High scores in categories aside from vigor indicate that a participant has a negative mood which would likely impact both exercise as well as perceived pain intensity. A study published in 2013 found that in individuals with chronic pain following a spinal cord injury where the pain was rated at 4 or higher (on a 0-

10 scale) had a significantly elevated depressed mood, anxiety, anger, fatigue confusion and significantly lower vigor (Rodrigues et al., 2013). Because pain has an impact on POMS scores, it is important to give the questionnaire prior to exercise. Additionally, depression and anxiety play a role in exacerbation of pain (Woo, 2010). Following completion of data collection, POMS scores were compared within participants and if too much variation occurs day to day, or if they scored too high in categories other than vigor, their data will not be included in the study.

The PAR-Q+ was given to participants during the first familiarization visit. This questionnaire was to determine if participants physically meet the criteria to participate in the study. The PAR-Q+ itself indicates if an individual can participate in exercise without the consent of a doctor or physician. With participants being recreationally active, it is likely that they can exercise without consent, but it alerts researchers to diagnoses of joint issues that may be exacerbated in this study. For the health and safety of participants, as well as for the accuracy of data, participants did not participate in the study if they have had surgery on either knee, or if they have had a knee injury within the last 6 months. This survey alerted researchers to either of those qualities. Additionally, if a participant checked "yes" on any of the boxes and did not presently have physician consent to exercise at high intensities, they were not allowed to participate. However, if they selected "yes" and had doctor consent they were allowed to participate.

Participants in this study were required to be recreationally active. To determine the activity level, the international physical activity readiness questionnaire (IPAQ). This questionnaire breaks down the activity level of each participant, as well as the type of exercise being completed. For this study, recreationally active is defined as meeting the ACSM's guidelines for physical activity which are at least 150 minutes of moderate intensity exercise or

60-75 minutes of vigorous exercise in addition to 2 days of resistance training. Due to the nature of the population being assessed, there will be no cap to how much participants exercise, but participants that are accumulating greater than 300 minutes of moderate intensity exercise and more than 150 minutes of vigorous exercise are considered very highly trained (McKay et al., 2021).

A third questionnaire that was completed by participants is the pain catastrophizing scale (PCS) which is used to determine how an individual responds and copes with pain. The PCS is a 13-item questionnaire that examines magnification, rumination, and helplessness with the intent of seeing how pain impacts an individual in those three categories (Osman et al., 2000). Pain catastrophizing is a psychological factor that impacts pain response as well as disability that is thought to be an emotional regulator when exposed to pain (Petrini et al., 2020). There is no health risk if a participant tends to lean towards pain catastrophizing, however results of this survey will be used for secondary analysis to determine how results of this questionnaire relate to exercise performance when exposed to knee pain stimulus.

In addition to the PCS, the pain attitudes questionnaire (PAQ) was used to gain a better understanding of participants willingness to admit that they are in pain, as well as the way that they describe the pain being experienced. The PAQ is designed to measure stoicism and cautiousness (Yong et al., 2001). Additionally, the questionnaire can breakdown the stoicism category and measure willingness to admit pain, and ability to control and tolerate pain. This questionnaire was used as a secondary analysis to determine how willing participants were to admit pain and see if there are correlations between results of this questionnaire to exercise performance and pain threshold measures.

The final questionnaire that was given to female participants is the menstrual cycle

regularity questionnaire. This alerted researchers to the regularity of the menstrual cycle as well as if participants are consuming hormonal birth control so that data collection for visits 3-5 could be scheduled during the luteal phase of the menstrual cycle. Participants were included in this study if they had a menstrual cycle between 21 and 35 days and if they were not pregnant. Because testing will occur in the luteal phase of the menstrual cycle, females taking hormonal birth control were included.

Electrically Induced Knee Pain

Participants had a pair of electrodes attached to both knees over the medial and lateral infrapatellar fat pads on the distal portion of the knee (Gallina et al., 2021). However, stimulation was only be applied to 1 knee during each testing session where pain is required. Electrodes were attached, but no stimulation will be applied during the TTF portion of the control session. A sinusoidal electrical stimulus was delivered at a frequency of 10 Hz using a constant-current stimulator (STIMISOLA; Biopac Systems Inc.). Stimulation began at an intensity of 10 mA and increased slowly in 5 mA increments until the participant indicated the stimulation became stronger and neared what they would consider “faint pain” or a 0.5/10. To more precisely establish a threshold stimulation intensity, the stimulation was increased and decreased in 1 mA increments in a stair-step fashion once a participant indicates its it painful to determine the required stimulation intensity to establish pain threshold. Once the signal is painful and a threshold stimulus had been established, stimulation intensity was increased in the same stair step manner until the participant rated the pain stimulus a 4 out of 10 (“somewhat strong pain”) on the pain intensity scale. After the participant’s pain level had reached a 4/10 following the gradual increase, the pain stimulus was stopped, and the participant will rested while the twitch

interpolation was calculated. To check that the electrical stimulus required to elicit a pain rating of 4/10 had not changed, it was checked when the electrical stimulator was turned on 5 seconds before MVCs 3 and 4 of the pre-exercise protocol. These measures were taken at the beginning of each of the five days to determine the necessary pain stimulus and to determine the reliability of both the electrical pain threshold and the intensity of stimulation required to evoke a pain intensity of 4/10 across the testing days.

To determine the effects of knee pain on maximal strength, the stimulation required to evoke a rating of 4/10 was applied to the knee for 5 seconds prior to and throughout the performance of a 3 second maximal contraction. During the TTF test, the appropriate knee was stimulated at the intensity evoking a rating of 4/10 continuously throughout the exercise protocol until failure was reached. Stimulation intensity was not adjusted during the fatiguing exercise, even if the evoked knee pain was no longer rated as a 4 out of 10. Additionally, the pain stimulus was immediately turned off at failure as the post exercise maximal contractions were designed to measure the difference in force recovery when pain location changes, not to determine if they are impacted by the presence or absence of pain.

Assessment of Maximal Voluntary Isometric Strength and Voluntary Activation

MVC and voluntary activation (VA%) will be measured in the knee extensor muscles of the dominant leg—assessed by asking the participant which leg they would use to kick a ball. If they did not know which leg is their dominant one based on that question, participants were asked to close their eyes and stand with their feet shoulder width apart. A series of random questions was asked and when they were not expecting it, they were lightly pushed in their back. Whichever foot they stepped forward with is their dominant leg. Knee extension force was recorded using a KinCom dynamometer (KinCom, Chattanooga, TN). Participants were seated

with their hip at a 90° angle and their knee at 100° of extension. Their lower leg was attached to the dynamometer at the shin using an inelastic strap. Force data from the KinCom was sent to a Biopac MP150 data collection module (Biopac systems Inc., Goleta, CA). Force data produced by the participant was visualized using Acknowledge software (Acknowledge v4.4, Biopac Systems Inc., Goleta, CA) and displayed to participants in real-time as biofeedback on a monitor.

Direct muscle stimulation was used to perform the twitch-interpolation technique to assess VA%. Stimulation electrodes (3" x 4" Axelgaard, Fallbrook, CA) were placed over the proximal muscle belly of the vastus lateralis and the distal belly of the vastus medialis to generate a large electrical field that stimulates the entire knee extensor muscle group. Initially, the stimulation current required to evoke a maximal muscle "twitch" will be determined. This will be done by applying a twitch, or 0.2ms stimulation to the muscle. A twitch is used to measure central fatigue by comparing contraction peaks, but also ensuring that a true maximal contraction was reached by preventing reuptake of calcium into the sarcolemma. Stimulation was applied by a constant current stimulator (DSA7H; Digitimer, Hertfordshire, UK) controlled by a custom written program script in Acknowledge software. Current was increased in 20 mA intervals until the observed force from the knee extensors no longer increases. This force plateau was checked by doing a p-p analysis of each twitch until the subsequent twitch no longer increased. This current level was recorded but was not used for subsequent visits because the amount of electrical stimulation varies daily based on things as minimal as hydration status.

Once maximal muscle stimulation current has been determined, MVCs were performed in the knee extensors. Participants were asked to contract their knee extensors as forcefully as possible and hold the contraction for 3 seconds. Strong verbal encouragement will be provided during this 3-sec contraction. Approximately 2.5 seconds into the contraction, a twitch

stimulation was applied to the muscle and any increase in force above what was generated during the maximal voluntary contraction was seen visually (this is termed the interpolated twitch force; IT) and recorded. Participants then relaxed their contraction of the knee extensors. An additional twitch stimulation was applied between one and two seconds after relaxation has begun. Force from these post contraction stimulations was termed "twitch force" (TF). Voluntary activation percentage will be calculated using the following equation: VA% = [(1-IT)/TF] x 100%.

Assessment of Critical Torque (CT) and Prescribed Submaximal Exercise Intensity

A Critical torque (CT) test was given during the second familiarization visit and used to determine an individual's critical torque and the prescribed intensity at which participants would be completing their time-to-task failure exercise. Prior to the 4 pre-exercise MVC contractions (2 without pain and 2 with pain), participants completed a five-minute CT test consisting of 30 maximal contractions 6 seconds on and 4 seconds off. The critical torque of the participant was the average of the final six maximal contractions of the CT test with the weight of their leg (in Newtons) subtracted from the average. CT was recorded and used to determine the intensity of submaximal exercise for the time-to-task failure test. Participants were prescribed exercise at 15% above their critical torque. 15% above CT was decided upon because it is high enough over critical torque that fatigue will be reached and that the fluctuation in the contraction does not dip below CT. It is also low enough that fatigue would not occur immediately and ideally would allow the participant to continue exercise for approximately 3-4 minutes. Participants that had a critical torque closer to their MVC would not be able to exercise if participants whose critical torque was drastically below their maximal strength.

Electromyography (EMG)

Electrical activity of the muscle was collected by use of electromyography (EMG). Use of EMG has been proven to be both reliable and valid as an index of the total electrical activity (which scales to force production/strength) of a muscle by Mathur et al. (2005) during repetitive muscle contractions. Pairs of bipolar EMG electrodes (interelectrode distance of approximately 20mm) will be placed over the rectus femoris and distal vasus medialis as suggested by SENIAM recommendations (Hermens, 1999) with a grounding electrode placed on the patella of the knee that is not receiving electrically induced pain stimulus. EMG signals will be collected using a wireless EMG system (BioNomadix; Biopac Systems Inc, Goleta, CA) and sampled at 2000 Hz. Signals will be high and low pass filtered using cutoff frequencies of 10 Hz (high pass) 500 Hz (low pass). The Biopac data collection template was set to collect raw EMG signal. Following completion of data collection, root mean square (RMS) and median frequency analysis will be performed to assess the magnitude (RMS) and frequency component of the EMG signal during each contraction of the TTF test.

Submaximal Fatiguing Exercise

The fatiguing exercise protocol was also be performed on the Kincom dynamometer. Intermittent contractions lasting 6 seconds followed by 4 seconds of rest were performed. The target force during the contractions was 15% above CT as determined on familiarization testing day 2. This protocol has been modified from that previously used by Pethick et al. (2016) and the intensity of 15% of CT has been chosen as it is known to be over critical torque whereas 60% of MVC is shown in a majority of

female participants to be over CT but is not guaranteed (Chesbro unpublished observations; 2023). Participants received strong verbal encouragement and viewed their force production as biofeedback on a monitor that also displayed a custom power point (adapted from Grant Chesbro, PhD) indicating when they should contract and when they should relax. Exercise continued until participants were unable to reach their required target force for three consecutive 6 second contractions. After every 3rd contraction (approximately once every 30 seconds) direct muscle stimulation was applied during the 4 second rest period to determine resting muscle twitch force—to assess peripheral fatigue. Every six contractions (or once every minute) the participant performed a three second MVC with ITT followed by a four second rest. After the MVC contraction, the intermittent contractions at 15% over CT continued. Once the participant reached failure, the knee pain stimulus was immediately stopped and the first post exercise MVC began. MVC was reassessed at the end of each minute for a period of 5 minutes to measure recovery for force after the exercise protocol.

Pain Rating during Exercise

Participants provided a rating of their right knee pain, left knee pain, and exercising muscle pain throughout the duration of the fatiguing exercise protocol. In order to promote consistency and reduce confusion, pain was continuously rated in the same order (right knee, left knee, exercising muscle) regardless of pain location or leg dominance. These subjective measurements were taken every 3rd contraction submaximal contraction during the TTF task as well as after the 6th submaximal contraction or immediately before every MVC contraction during the fatiguing exercise. The pain of the knees and exercising muscle pain were recorded at failure, immediately after the 5-post

fatiguing MVC contractions, 30 seconds, and 55 seconds after the post exercise MVCs. The same 0-10 rating scale developed by Cook et al. (1998) will be used to obtain these numbers.

Data Management and Statistical Analysis

To prevent errors and increase inter-rater reliability, one researcher oversaw all of the objective measurement, and an assistant was present to record subjective measurements (such as pain) during and after exercise. All data was managed by one researcher and was stripped of any personal identifiers so that anonymity is maintained among participants. Additionally, a check sheet was filled out and initialed as each visit was completed to ensure that there are no missed steps and that all forms are filled out with no missing signatures.

Data was analyzed using SPSS version 28. Data was checked for normality with the use of a Shapiro-Wilk test. If data was not normally distributed the Greenhouse-Geiser correction was used in the ANOVAs. Differences in TTF, MVC, and force recovery among the 3 testing sessions (contralateral pain, ipsilateral pain, and no pain) were assessed using a 3x2 mixed model ANOVA. Follow-up testing using a t-test with a Bonferroni correction for multiple comparisons was used to assess differences among the 3 conditions if the ANOVA is significant. MVC, VA%, TF, and rating of muscle pain was assessed using a completely within measures ANOVA. Three conditions were used (contralateral pain, ipsilateral pain, and no pain) while the repeated time points within a given TTF trial include before fatiguing exercise, at one minute, the last usable MVC or twitch before failure, and the first post exercise MVC and twitch following failure. It is

possible that participants only made it through one during exercise MVC, so their one-minute MVC and last usable MVC was the same during the analysis. Pearson correlations will be calculated between MVC and TTF, pain threshold and TTF, and MVC and pain threshold. Significance will be set at $\alpha < 0.05$.

Chapter 4 - Results

There were 24 participants that consented to take part in this study. Twenty-two of the 24 participants completed all five visits and received compensation. Of the 22 participants that completed the study, twelve were men and nine were women. One individual chose not to disclose their sex. Since part of this project aims to determine if there is a sex difference in pain perception, fatiguability, and maximal strength, the individual who did not disclose their sex will be included in analysis of the participants as a whole but will be removed during specific sex comparisons.

Table 1 – Descriptive data of male and female participants.

Variable	Women (n = 9)	Men (n = 12)	All (n = 22)
Age (yr)	23.3 ± 3.7	23.7 ± 3.1	23.8 ± 3.5
Height (cm)	167.0 ± 7.7	174.2 ± 10.1[#]	171.3 ± 10.1
Weight (kg)	72.5 ± 19.9	84.8 ± 12.4	79.3 ± 15.1
Moderate PA (MET·min)	546.7 ± 865.6	778.3 ± 758.5	886.4 ± 1171.3
Vigorous PA (MET·min)	1577.8 ± 1177.0	1746.7 ± 2135.4	1609.1 ± 1736.9
Walking PA (MET·min)	1248.5 ± 763.6	1787.5 ± 2534.8	1512.8 ± 1923.8
Total PA (MET·min)	3372.9 ± 1751.5	4312.5 ± 2776.3	3988.2 ± 2357.4
CT (Nm)	110.2 ± 36.3	140.8 ± 38.2	127.8 ± 38.7
MVC (Nm)	147.5 ± 50.9	244.4 ± 53.9[#]	201.6 ± 69.6
Relative CT(%MVC)	65.8 ± 12.5	53.3 ± 16.6[#]	58.7 ± 15.6

Values are means ± SD (n=22)
[#]Significant main effect of sex ($p<0.05$)
PA = Physical Activity; MET = Metabolic equivalent; Nm = Newton meters, CT = Critical Torque, MVC = Maximum voluntary contraction, CT(%MVC) = critical torque expressed as relative to maximal strength

Descriptive variables for the sample are shown in Table 1. There was a significant difference between men and women in height, ($p=0.04$), but not in weight ($p=0.07$) or age ($p=0.10$). All participants met or exceeded the ACSM guidelines for weekly physical activity, but men and women did not differ in any assessed PA measure ($p \geq 0.39$).

Critical torque did not differ between men and women (p=0.08). As expected, men had a greater (stronger) MVC than women (p = 0.0005). Critical torque expressed relative to MVC (to account for differences in strength) was higher in women but did not reach statical significance (p=0.07). Interestingly, a significant negative relationship was found between MVC and relative CT (r = 0.57, p < 0.05, Figure 3).

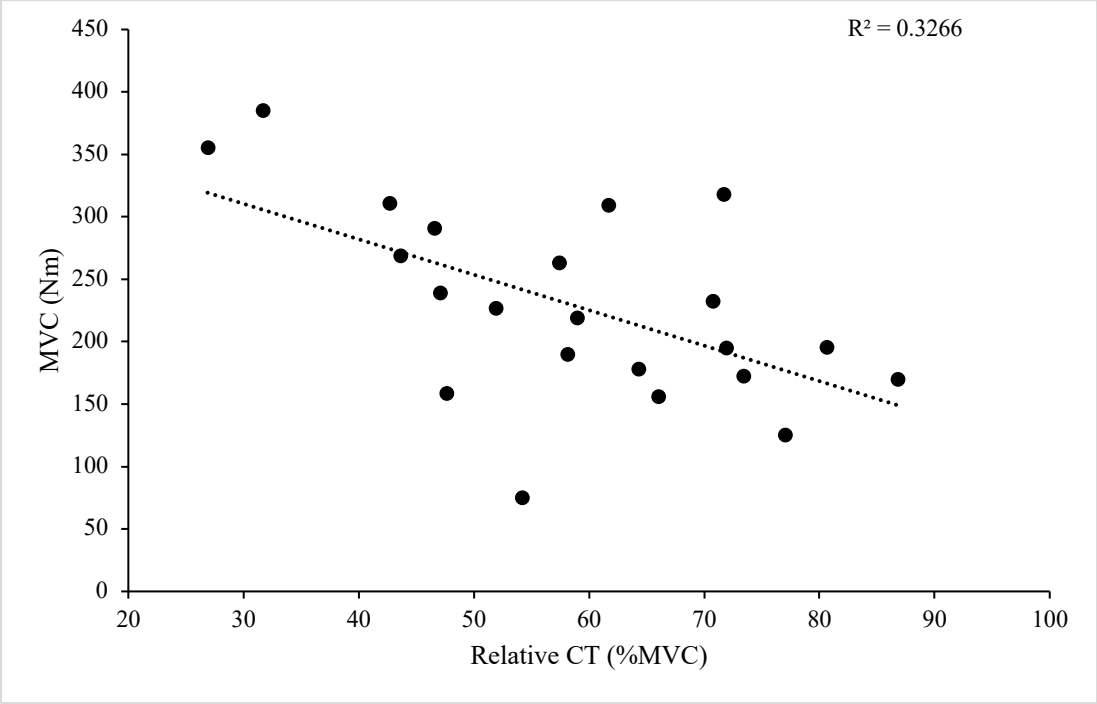

Figure 4 (above)– Relationship between relative critical torque and maximal strength (MVC).
Values are means ± SD (n=22)
MVC = maximum voluntary contraction, CT = critical torque, CT(%MVC) = CT expressed as percentage of MVC

Pain Threshold and Pain Questionnaires

Mean values for pain threshold, pain catastrophizing, and pain attitudes can be seen in Table 2. There was not a sex x knee interaction in regard to knee pain threshold and the current required to elicit a pain rating of "4" (p = 0.54) There was a main effect for the knee for both pain threshold measurement and current required to elicit a '4" (p ≤

0.002). There was not a main effect of sex ($p \geq 0.23$). When scoring the pain catastrophizing scale, the higher the number a person scores, the more extreme a catastrophizer they are. An independent samples t-test determined that there was not a statistically significant sex difference in the pain catastrophizing scores ($p = 0.63$). The pain attitudes questionnaire measures five distinct categories including stoic fortitude, stoic concealment, stoic superiority, cautious self-doubt, and cautious reluctance. An independent samples t-test found that there was no statistically significant difference in stoic fortitude ($p = 0.75$), stoic concealment ($p = 0.76$), stoic superiority ($p = 0.91$), cautious self-doubt ($p = 0.06$) or cautious reluctance ($p = 0.08$) between men and women.

Table 2 – Pain threshold and pain questionnaire on male and female participants

Variable	Women (n = 9)	Men (n = 12)	All (n = 22)
IL Knee Threshold (mA)	27.6 ± 6.0	33.2 ± 9.5	31.1 ± 8.4
CL Knee Threshold (mA)	25.7 ± 6.4	25.3 ± 8.2	25.3 ± 7.2*
IL Knee Pain @4 (mA)	44.5 ± 11.3	49.7 ± 8.1	47.5 ± 9.5
CL Knee Pain @4 (mA)	38.1 ± 6.3	40.6 ± 8.3	39.8 ± 7.3*
Pain Catastrophizing	7.6 ± 3.7	6.5 ± 7.3	7.0 ± 5.8
Stoic Fortitude	17.1 ± 3.2	17.5 ± 2.4	17.5 ± 2.7
Stoic Concealment	11.7 ± 1.9	11.3 ± 2.7	11.5 ± 2.3
Stoic Superiority	14.4 ± 3.3	14.6 ± 2.2	14.6 ± 2.6
Cautious Self-Doubt	16.4 ± 3.7	12.7 ± 4.5	14.5 ± 4.6
Cautious Reluctance	15.6 ± 3.6	12.8 ± 3.3	13.9 ± 3.5

Values are means ± SD (n=22)
*Significant main effect of pain ($p<0.05$)
IL = ipsilateral, CL = contralateral, mA = milliamps

Applied Knee Pain and Maximal Strength

Mean values for maximal strength, twitch torque, and voluntary activation can be seen in Table 3. A 2 (sex) x 2 (Pain vs No Pain) x 3 (IL pain, CL pain, or control) mixed model repeated measures ANOVA was run to determine the effects of sex and the application of knee pain on maximal strength. The three-way interaction was not

significant (p = 0.14). Additionally, there were no interactions for sex and the presence/absence pain (p = 0.07), sex and the location of knee pain (p=0.89), or between the presence/absence of knee pain and the location of knee pain (p=0.44). There was a main effect for sex (p < 0.001) with men demonstrating greater strength and a main effect for the presence of knee pain (p = 0.016) with pain resulting a lower MVC values.

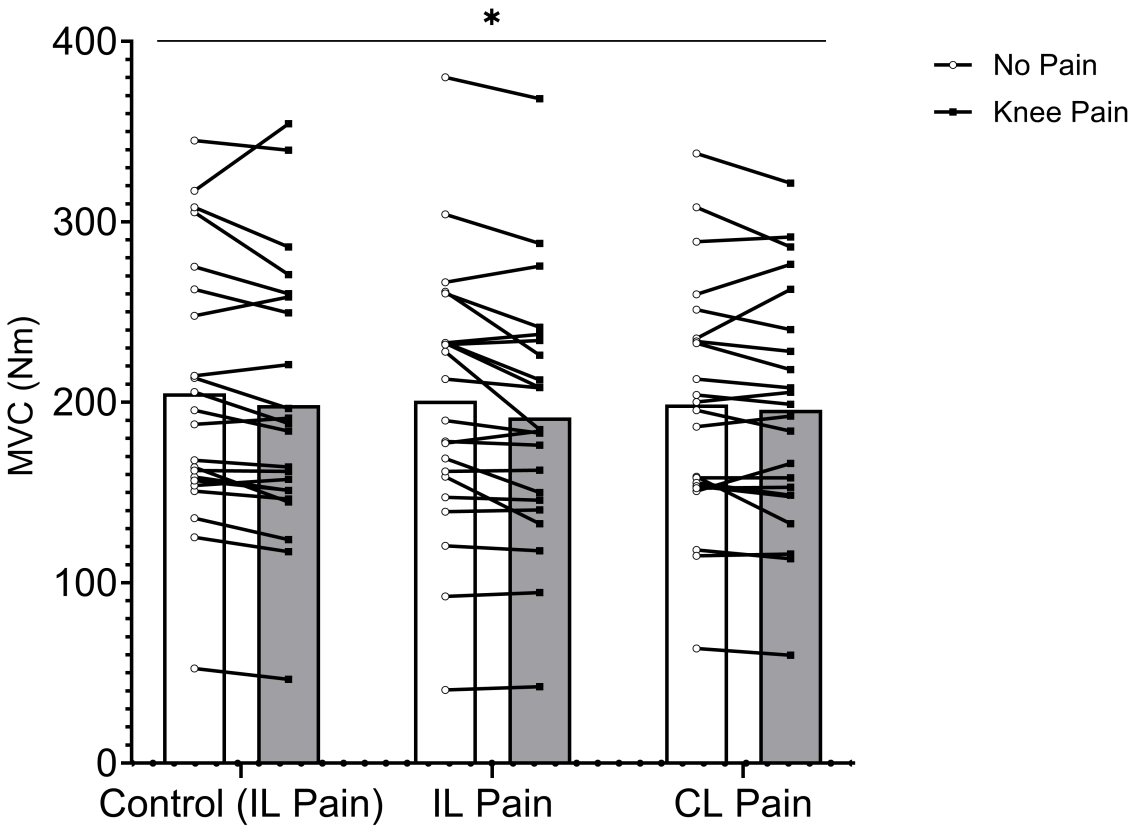

Figure 5 (above) - Maximal Strength following application of electrically induced knee pain
Values are means ± SD (n=21)
*Significant main effect of pain (p<0.05)
MVC = maximum voluntary contraction, Nm = Newton meter, IL = ipsilateral, CL = contralateral

Peripheral fatigue due to pain was assessed by comparing twitch forces with and without pain stimulus following maximal exercise. A similar 2 x 2 x 3 mixed model ANOVA was performed. No 3-way interaction was found (p = 0.43). It was also found

that there was no interaction between location of pain and sex ($p = 0.17$), presence/absence of pain and sex ($p = 0.68$), or pain location and pain presence/absence of pain ($p = 0.71$). There was no main effect for pain location ($p = 0.34$) and presence/absence of pain ($p = 0.06$) meaning that location of the knee pain, nor the presence of knee pain significantly impacted twitch force and peripheral fatigue. There was a significant sex difference in twitch forces ($p<0.001$) which is to be expected as it was previously determined that the men were stronger than the women.

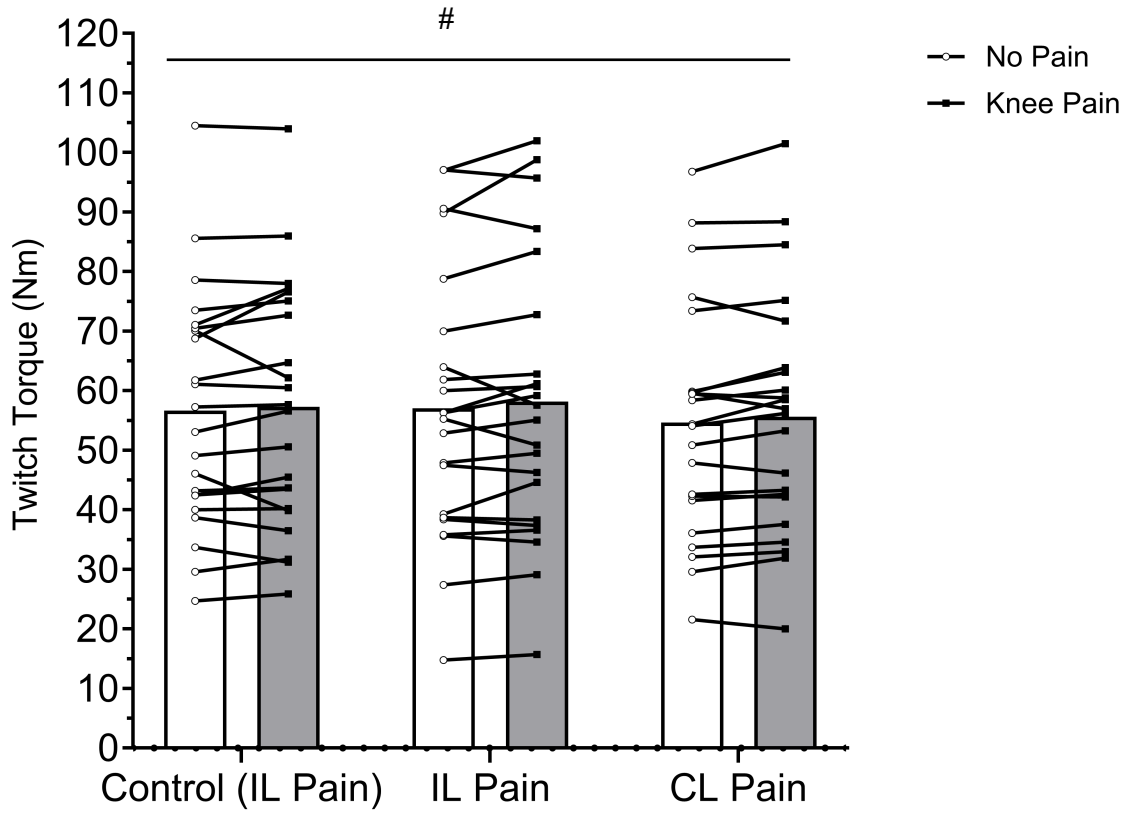

Figure 6 (above) - Twitch Torque following application of electrically induced knee pain
Values are means ± SD (n=21)
#Significant main effect of sex ($p<0.05$)
Nm =Newton meters, IL = ipsilateral, CL = contralateral

A similar 2 x 2 x 3 mixed model ANOVA was performed to determine if there was a change in central fatigue with the pain stimulus applied to the knee. The three-way

ANOVA was not significant (p=0.63). It was also found that there was no interaction between location of pain and sex (p = 0.79), presence/absence of pain and sex (p = 0.72), or pain location and pain presence/absence of pain (p = 0.14). There was not a main effect of pain location (p = 0.40) and there was also no main effect of sex (p = 0.36). It was however determined that there was a main effect of the presence/absence of pain (p < 0.001) with the application of pain resulting in a reduction in percent motor unit recruitment/activation

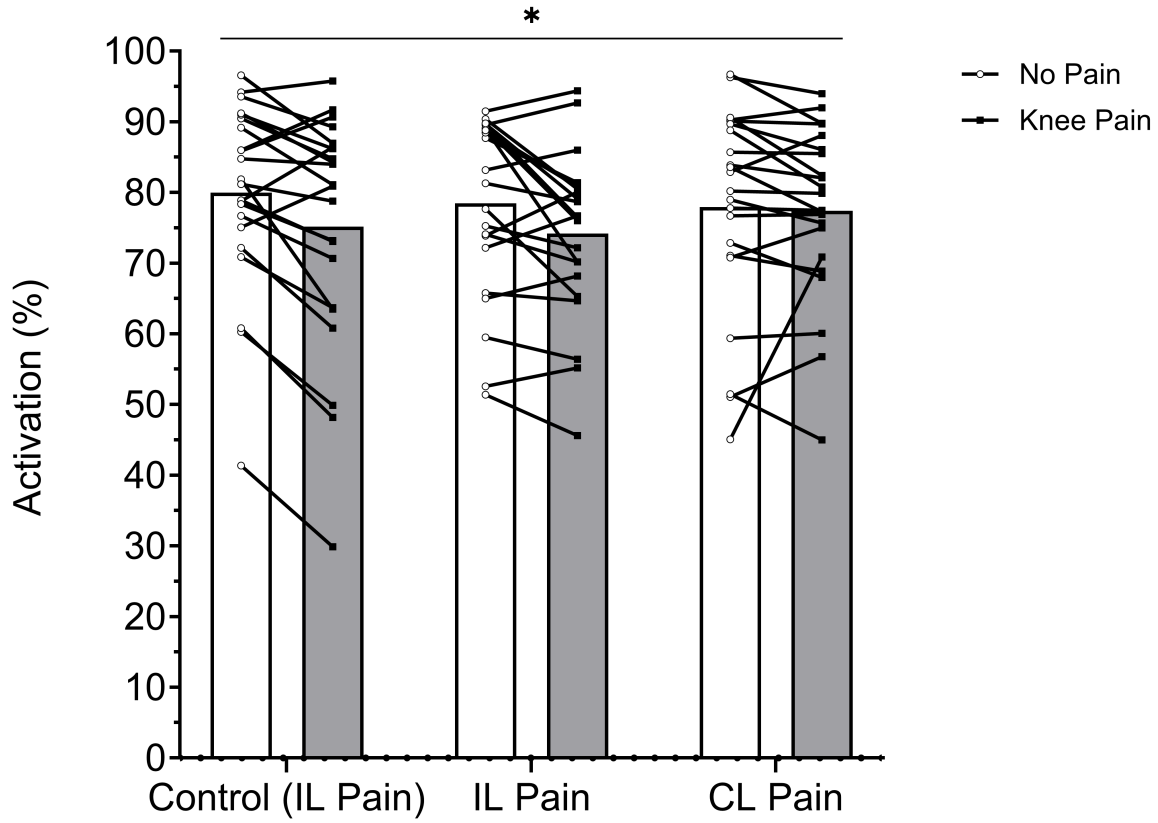

Figure 7 (above) - Voluntary activation following application of electrically induced knee pain
Values are means ± SD (n=21)
*Significant main effect of pain (p<0.05)
IL = ipsilateral, CL = contralateral

Surface Electromyography was used to determine the electrical activity and muscle activation of the exercising muscle. The impact of pain on muscle activation during maximal strength exercise was examined with a 3 (condition) x 2 (time point) x 2

(sex) repeated measures ANOVA and it was found that there was no significant 3-way interaction (p=0.18), no 2-way interactions were found between condition and pain (p=0.66), pain and sex (p=0.3), or condition and sex (p=0.18). There was no main effect of condition (p=0.66) or sex (p=0.3). There was a main effect of pain (p=0.007). It was found that muscle activation decreased from 100% to 88.41% with the application of knee pain regardless of pain location.

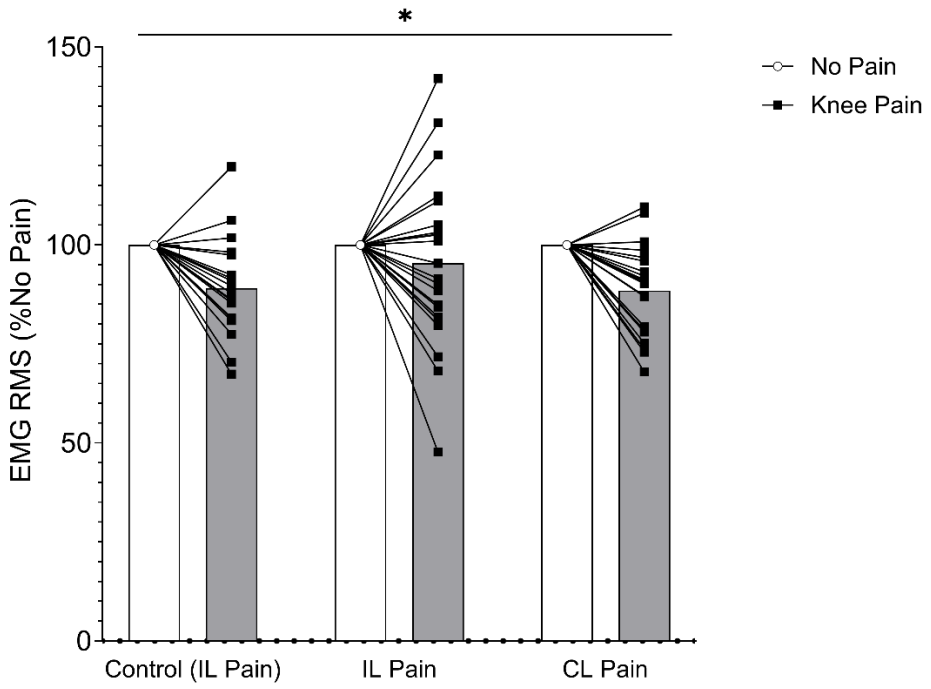

Figure 8 (above) – EMG RMS, expressed relative to values when no painful stimulation was applied. Values are means ± SD (n=21)
*Significant main effect of pain ($p<0.05$)
EMG = electromyography, RMS = root mean square, IL = ipsilateral, CL = contralateral

It was determined with the use of a Pearson correlation that there were significant relationships between the change in MVC, the change in voluntary activation, and the change in EMG signals. When the change in MVC was correlated with the change in

voluntary activation, there was a statistically significant relationship (p=0.002) that produced an R^2 value of 0.14.

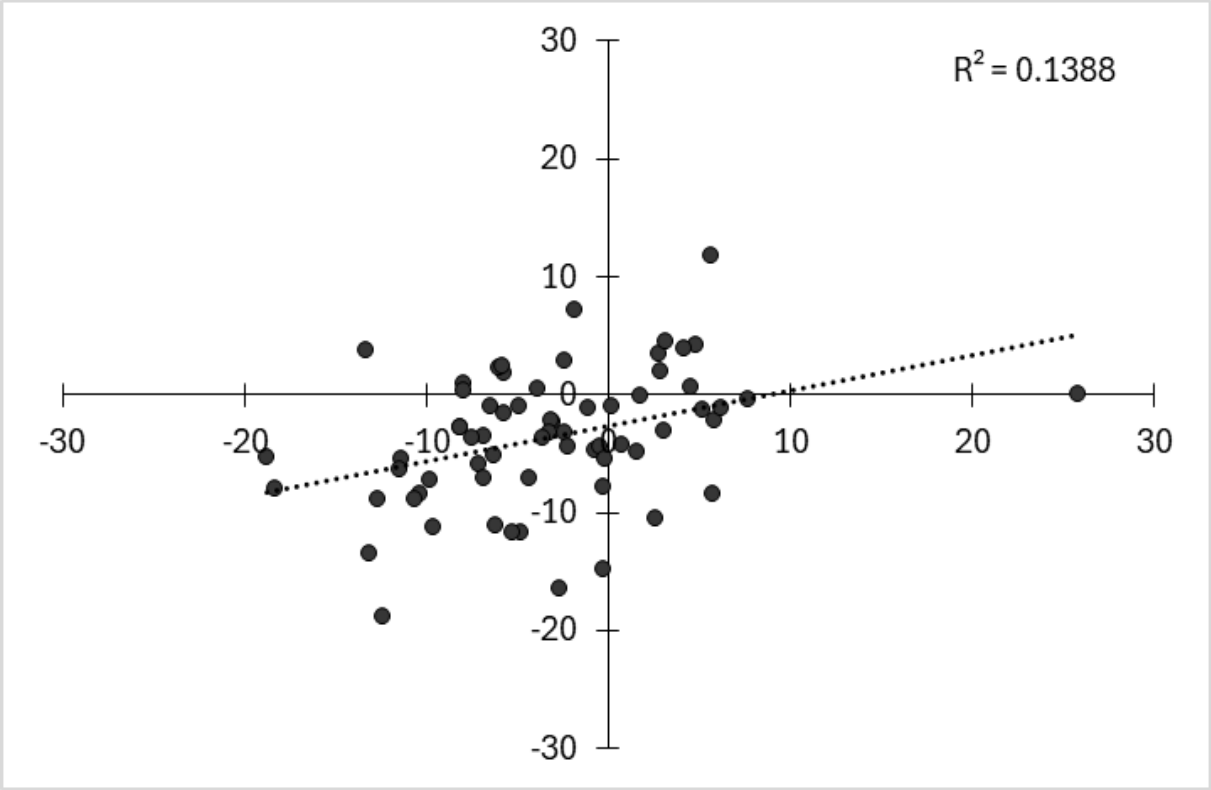

Figure 9 (above) – The relationship of %VA and percent change of maximal strength values with no pain stimulus applied.
Values are means ± SD (n=21)
%VA = voluntary activation, MVC = Maximal strength,

It was also found that when maximal strength was correlated to EMG, there was a statistically significant positive correlation (p=0.006) that produced an R^2 value of 0.12.

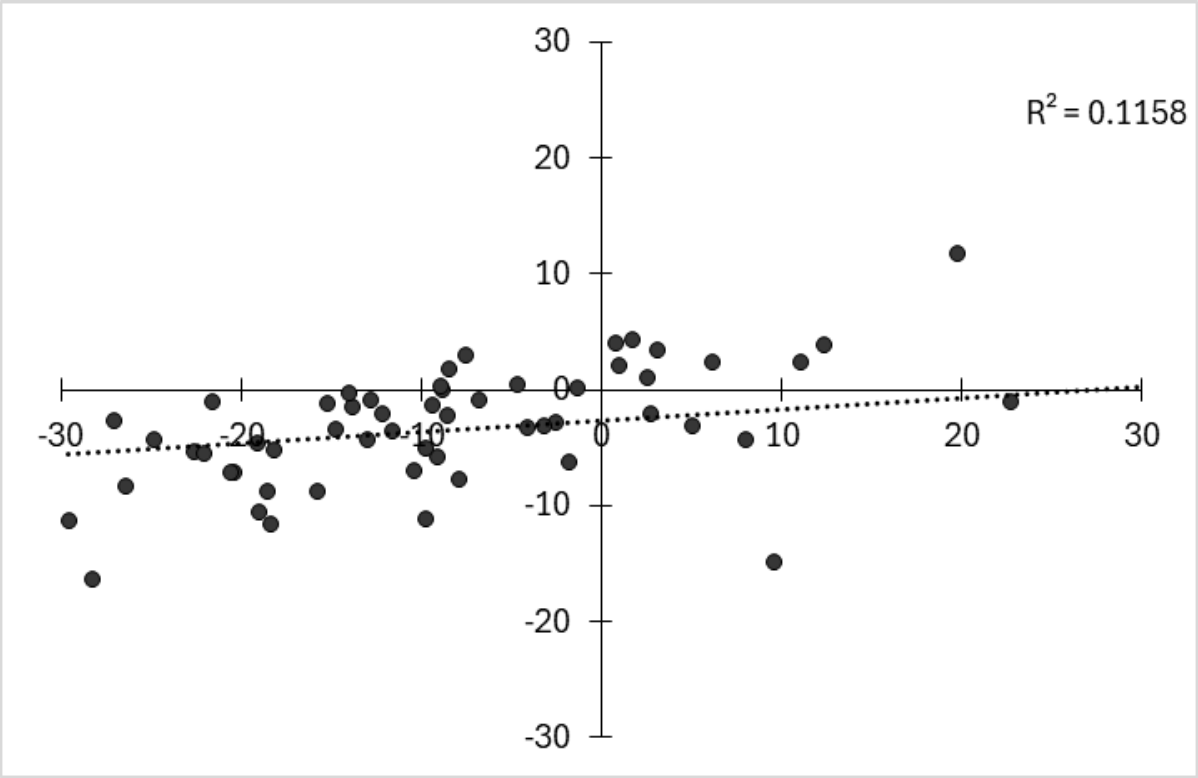

Figure 10 (above) – The relationship of surface EMG electrical activity and percent change in maximal strength values with no pain stimulus applied.
Values are means ± SD (n=21)
EMG = electromyography, MVC = maximum voluntary contraction.

This indicates that when maximal strength is decreased, it is likely due to a decrease in central mechanisms. When there is an increase in maximal strength, it is also likely due to central mechanisms.

Table 3 – Maximal strength, twitch torque, and voluntary activation with and without the application of knee pain.

Variable	Women (n = 9)	Men (n = 12)	All (n = 22)
MVC			
Control – No Pain (Nm)	151.3 ± 50.6	249.6 ± 60.0#	204.9 ± 73.3
Control – Pain (IL) (Nm)	148.0 ± 55.4	240.6 ± 64.7#	198.4 ± 74.8*
IL – No Pain (Nm)	144.6 ± 56.6	245.8 ± 57.5#	200.9 ± 74.1
IL – Pain (Nm)	145.0 ± 56.0	230.0 ± 60.6#	191.6 ± 70.5*
CL – No Pain (Nm)	146.6 ± 49.9	237.6 ± 52.9#	198.9 ± 66.7
CL – Pain (Nm)	144.8 ± 48.6	234.0 ± 54.4#	195.9 ± 66.3*
Twitch Torque			
Control – No Pain (Nm)	40.7 ± 13.1	69.2 ± 15.6#	56.6 ± 19.9
Control – Pain (IL) (Nm)	41.7 ± 14.9	69.5 ± 16.4#	57.3 ± 19.9
IL – No Pain (Nm)	38.1 ± 11.6	71.4 ± 19.3#	57.1 ± 22.8
IL – Pain (Nm)	39.2 ± 11.7	73.0 ± 20.5#	58.2 ± 23.6
CL – No Pain (Nm)	39.4 ± 11.0	66.3 ± 17.9#	54.6 ± 19.8
CL – Pain (Nm)	39.5 ± 10.3	67.9 ± 179#	55.6 ± 20.1
Percent Activation			
Control – No Pain (Nm)	74.8 ± 15.1	83.1 ± 11.1#	80.0 ± 13.1
Control – Pain (IL) (Nm)	72.0 ± 20.2	77.0 ± 14.6#	75.2 ± 16.6*
IL – No Pain (Nm)	73.7 ± 13.6	81.3 ± 11.9#	78.5 ± 12.8
IL – Pain (Nm)	70.6 ± 12.3	76.3 ± 11.6#	74.2 ± 11.8*
CL – No Pain (Nm)	73.0 ± 15.8	81.0 ± 14.0#	77.9 ± 14.7
CL – Pain (Nm)	73.4 ± 12.8	79.8 ± 11.7#	77.4 ± 12.1*

Values are means ± SD (n=21)
#Significant main effect of sex ($p<0.05$)
*Significant main effect of pain ($p<0.05$)
MVC = maximum voluntary contraction, Nm = newton meters, IL = ipsilateral, CL = contralateral

Knee Pain and Time-to-Task Failure

A 3 (knee pain condition) by 2 sex (men vs women) mixed model ANOVA found no significant interaction between condition and sex ($p = 0.43$). Nor was there a main effect among the conditions ($p = 0.15$) or a main effect between the sexes ($p = 0.54$). After observing no sex difference, the entire population (9 women, 12 men, 1 trans individual) was analyzed with a one-way repeated measures ANOVA which showed there was no effect of knee pain ($p=0.21$) on TTF.

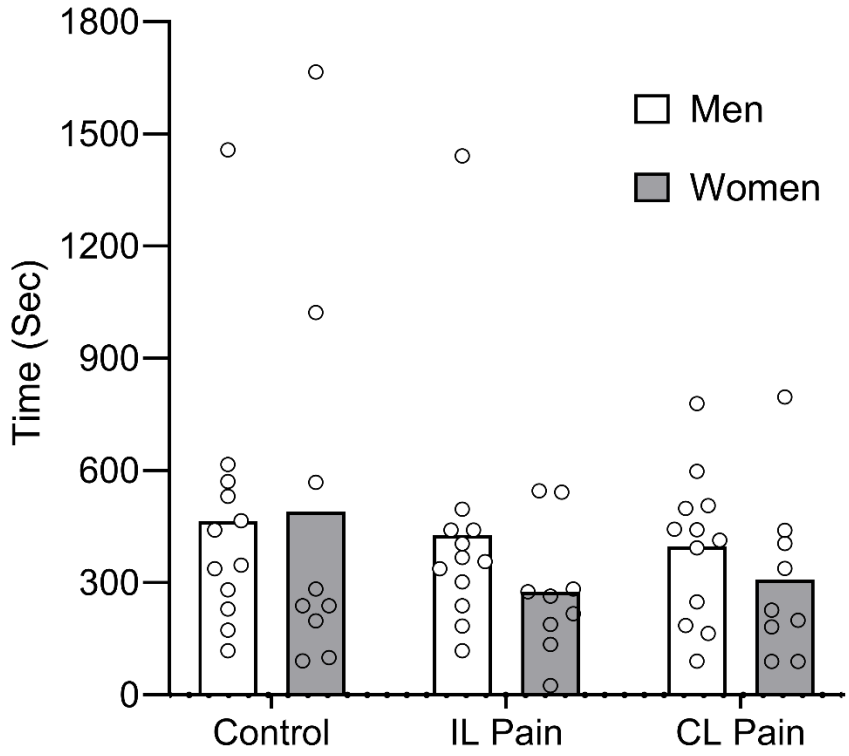

Figure 11 (above) – The time-to-task failure of men and women with pain stimulus in different locations. Values are means ± SD (n=21)

Average values for time-to-task failure in each condition can be found in table 3, where the means correspond to values shown in figure 4.

Table 4– Time-to-task Failure of men and women with pain stimulus in different locations

Variable	Women (n = 9)	Men (n = 12)	All (n = 21)
TTF with IL Pain (sec)	275.52 ± 172.42	427.56 ± 337.97	362.4 ± 284.00
TTF with CL pain (sec)	307.94 ± 222.48	397.01 ± 197.14	358.84 ± 207.88
TTF with no pain (sec)	489.65 ± 528.9	464.47 ± 350.19	475.26 ± 423.68

Values are means ± SD (n=21)
TTF = time-to-task failure, IL = ipsilateral, CL = contralateral

Fatigue Parameters During Time-to-Task Failure

In the analysis of fatigue measures and maximal strength during exercise, one female participant was excluded due to her short time to task failure. This participant only

lasted 25.2 seconds which resulted in them to not make it to the first assessments of twitch torque, pain ratings, or MVC. As such the groups are 12 men and 8 women. MVC during the task was expressed as a percentage of pre-exercise MVC to account for differences among participants. Because of the difference in TTF among conditions and participants, MVC after 60 seconds of exercise, the last assessed MVC, and the MVC performed immediately after task failure was reached was reported. For example, if a person only lasted 1 minute and 10 seconds, then their second and third time point would be the same, however if a person lasted 27 minutes, then their third time point would be their 27th MVC.

Data for MVC during exercise can be found in Table 4. The 3 knee pain conditions x 4-time points x 2 sexes mixed model repeated measures ANOVA yielded a non-significant 3-way interaction between condition, time, and sex ($p = 0.24$). It also showed that there was no 2-way interaction between condition and sex ($p = 0.20$), time and sex ($p = 0.18$), or condition and time ($p = 0.52$). Lastly, there was no main effect for condition ($p = 0.46$) or sex ($p = 0.22$). There was, however, a main effect for time ($p < 0.001$). Follow-up analysis found MVC 60-seconds into exercise was not statistically different from the starting force ($p = 0.63$). The last measured MVC during fatiguing exercise showed an 19% decrease in force compared to pre ($p < 0.001$) and the immediately post exercise MVC showed a 23% decrease ($p < 0.001$) compared to pre.

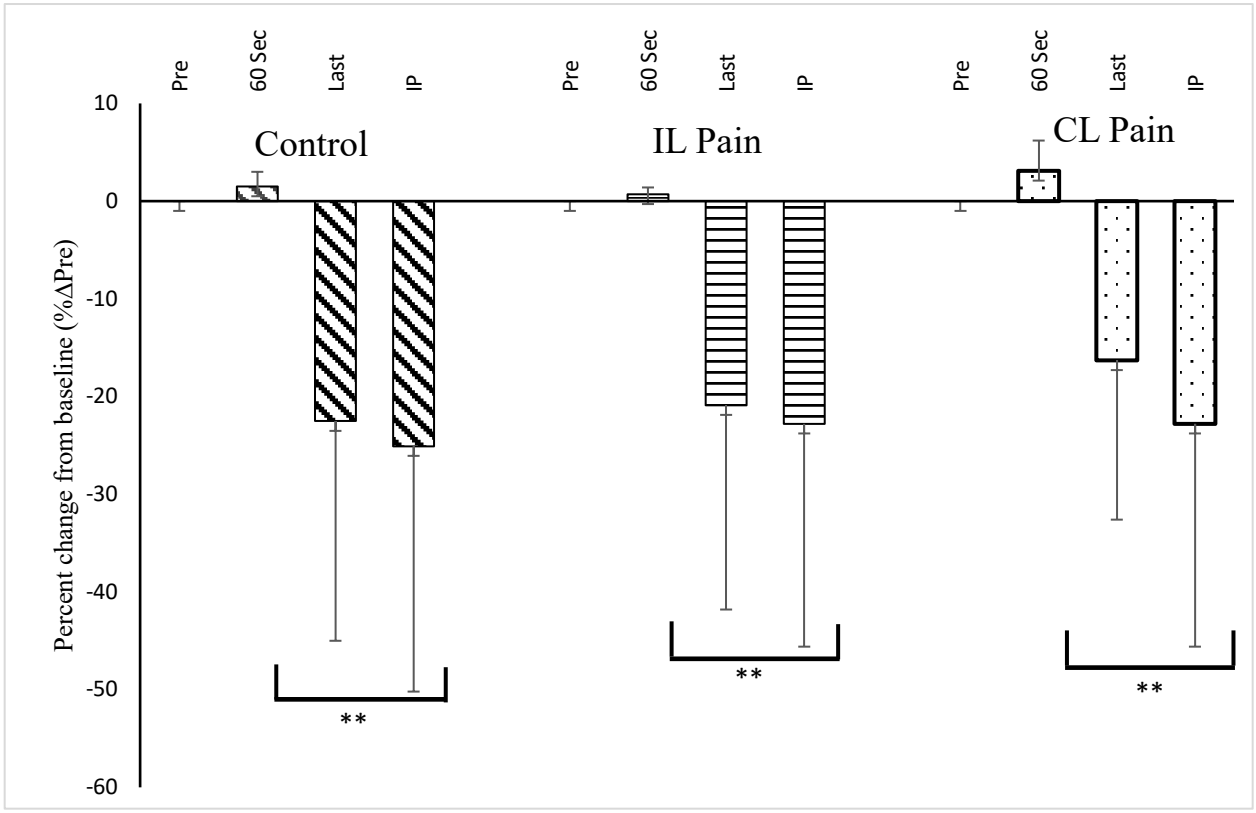

Figure 12 (above) - Maximum voluntary force decline throughout submaximal fatiguing exercise.
Values are means ± SD (n=22)
**Significant main effect of time ($p<0.05$)
%ΔPre = percent change from baseline values, IL = ipsilateral, CL = contralateral, pre = baseline values, last = last usable maximal contraction, IP = immediately post failure.

Peripheral Fatigue During Submaximal fatiguing exercise

Because it was collected every 30-seconds during the TTF test, data for twitch torque is reported at 30-sec and 60-sec into exercise as well as the last measured time point and immediately post exercise. Twitch torque data during exercise can also be found in Table 4 and is reported as a percent change from Pre exercise values. The 3 knee pain conditions x 4-time points x 2 sexes mixed model repeated measures ANOVA yielded a non-significant 3-way interaction between condition, time, and sex ($p = 0.61$). It also showed that there was no 2-way interaction between condition and sex ($p = 0.66$), time and sex ($p = 0.11$), or condition and time ($p = 0.65$). Lastly, there was no main effect

for condition ($p = 0.59$) or sex ($p = 0.11$). There was, however, a main effect for time ($p < 0.001$). Follow-up analysis found twitch torque 30-seconds into exercise had increased (9%; $p < 0.001$), values 60-seconds into exercise did not differ statistically different from pre ($p = 0.98$), the last measured TT during fatiguing exercise showed an 44% decrease in force compared to pre ($p < 0.001$) and the immediately post exercise MVC showed a 48% decrease ($p < 0.001$) compared to pre.

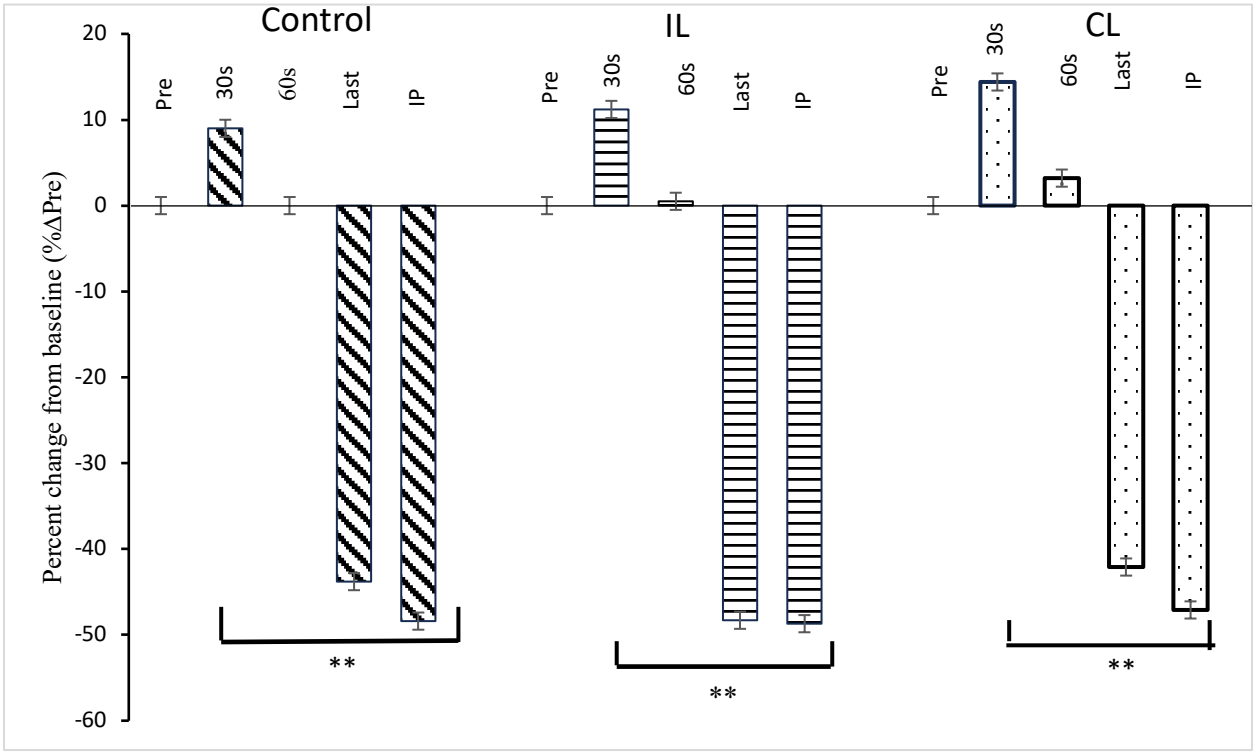

Figure 13 (above) - Twitch Torque decline throughout submaximal fatiguing exercise.
Values are means ± SD (n=22)
**Significant main effect of time ($p<0.05$)
%ΔPre = percent change from baseline values, IL = ipsilateral, CL = contralateral, pre = baseline values, last = last usable maximal contraction, IP = immediately post failure.

Central Fatigue During Submaximal Fatiguing Exercise

Central fatigue was analyzed in all participants except for the same female who was excluded due to her extremely short time-to-task failure. As was done for MVC, data

from Pre exercise, after 60 seconds of exercise, the last assessed %ACT, and %ACT from the MVC performed immediately after task failure were reported. Data can be found in Table 4. The 3 knee pain conditions x 4-time points x 2 sexes mixed model repeated measures ANOVA yielded a non-significant 3-way interaction between condition, time, and sex ($p = 0.11$). It also showed that there was no 2-way interaction between condition and sex ($p = 0.53$), time and sex ($p = 0.18$), or condition and time ($p = 0.10$). Lastly, there was no main effect for condition ($p = 0.44$). There was, however, a main effect for time ($p < 0.001$) and sex ($p = 0.03$). Over time %ACT increased compared to Pre at the 60-sec time point ($p = 0.008$), did not differ from Pre at the last measured time point or immediately post exercise ($p \geq 0.22$).

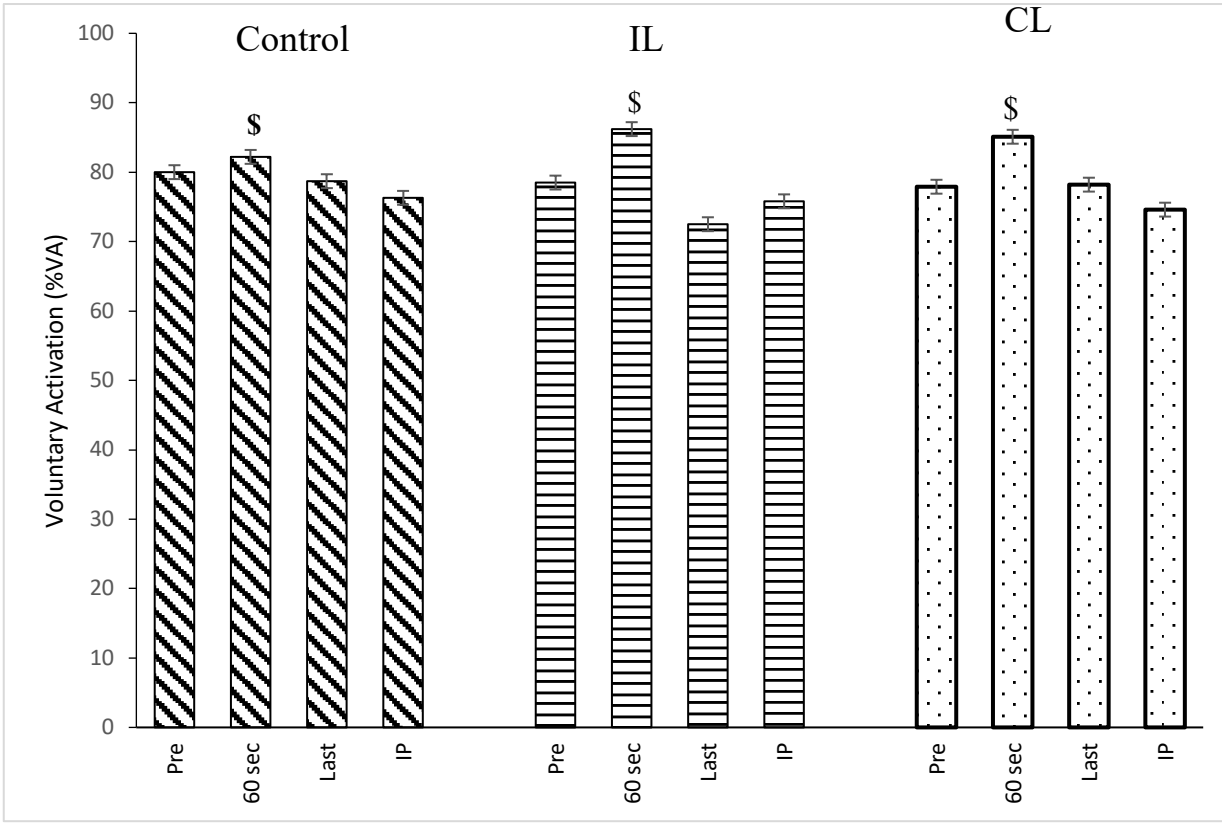

Figure 14 (above) - Voluntary Activation decline throughout submaximal fatiguing exercise.
Values are means ± SD (n=22)
$ Significant difference (main comparison) from "Pre" values (main comparison; $p < 0.05$)
%ΔPre = percent change from baseline values, IL = ipsilateral, CL = contralateral, pre = baseline values, last = last usable maximal contraction, IP = immediately post failure.

In order to measure muscle activation during fatiguing submaximal exercise, A 3 (condition) x 7 (time point) x 2 (sex) within subjects repeated measures ANOVA was used to examine the change in muscle activation. There was no 3-way interaction ($p=0.79$), no 2-way condition by time interaction ($p=0.85$), no 2-way time by sex interaction ($p=0.2$), no 2-way condition by sex interaction ($p=0.45$), no main effect of condition ($p=0.75$) and no main effect of sex ($p=0.94$). There was a main effect of time ($p=0.04$). When compared to the final usable submaximal contraction of the fatiguing exercise protocol, the final contraction was not different from the first submaximal

contraction of the protocol (p=0.07), but it was different from submaximal contractions two (p=0.03), three (p=0.04), four (p=0.03), five (p=0.03) and six (p=0.02).

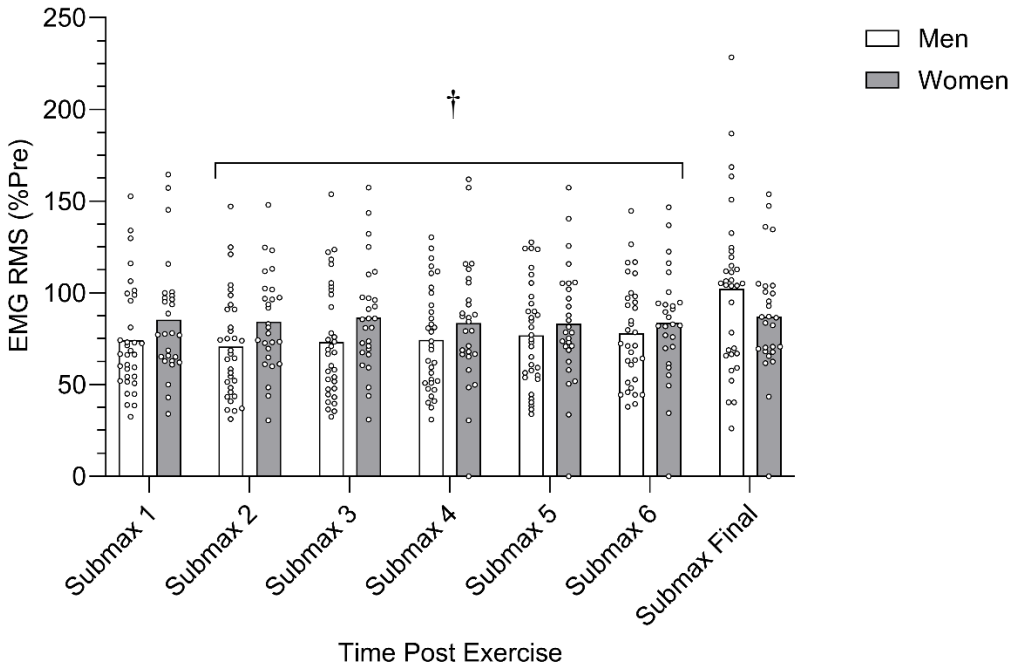

Figure 15 (above) – EMG RMS, expressed relative to pre MVC values across the first minute of submaximal exercise and at task failure.
Values are means ± SD (n=22)
† Significant difference (main comparison) from the value at task failure ($p<0.05$)
%ΔPre = percent change from baseline values, IL = ipsilateral, CL = contralateral, pre = baseline values, last = last usable maximal contraction, IP = immediately post failure.

Table 5– Maximal strength, twitch torque and percent activation with and without the application of knee pain during fatiguing exercise.

Variable	Control	IL	CL
MVC			
Pre-Exercise	0.0	0.0	0.0
60-seconds (%ΔPre)	1.5 ± 12.0	0.7 ± 12.9	3.1 ± 18.7
Last Measured (%ΔPre)	-22.5 ± 19.2	-20.9 ± 20.4	-16.3 ± 25.7
Immediately Post (%ΔPre)	-25.1 ± 17.5	-22.8 ± 19.8	-22.8 ± 18.4
Twitch Torque			
Pre-Exercise	0.0	0.0	0.0
30-seconds (%ΔPre)	9.0 ± 10.0	11.2 ± 4.5	14.4 ± 20.6
60-seconds (%ΔPre)	0.0 ± 14.2	0.5 ± 16.2	3.2 ± 18.6
Last Measured (%ΔPre)	-43.8 ± 33.6$^{\$}$	-48.3 ± 28.2$^{\$}$	-42.1 ± 31.2$^{\$}$
Immediately Post (%ΔPre)	-48.4 ± 35.2$^{\$}$	-48.7 ± 28.9$^{\$}$	-47.1 ± 29.2$^{\$}$
Percent Activation			
Pre-Exercise (%)	80.0 ± 13.1$^{\#}$	78.5 ± 12.8$^{\#}$	77.9 ± 14.7$^{\#}$
60-seconds (%)	82.2 ± 15.8$^{\$\#}$	86.2 ± 7.3$^{\$\#}$	85.1 ± 10.8$^{\$\#}$
Last Measured (%)	78.7 ± 16.1$^{\#}$	72.5 ± 27.0$^{\#}$	78.2 ± 15.4$^{\#}$
Immediately Post (%)	76.3 ± 17.3$^{\#}$	75.8 ± 14.6$^{\#}$	74.6 ± 21.2$^{\#}$

Values are means ± SD (n=22)
$^{\#}$Significant main effect of sex ($p<0.05$)
$^{\$}$ Significant difference (main comparison) from "Pre" values (main comparison; $p < 0.05$)
IL = ipsilateral, CL = contralateral, MVC = maximum voluntary contraction, %ΔPre = percent change from baseline values.

Post Exercise Force Recovery

Force recovery following fatiguing exercise was assessed using a 2 sex (men vs women) x 3 knee pain condition (Control, IL, CL) x 7 time point (pre, immediately pot, 1-5 minutes post) mixed model ANOVA. There was no 3-way interaction ($p = 0.20$). Additionally, there was no condition by time interaction ($p = 0.87$), condition by sex interaction ($p = 0.15$), or time by sex interaction ($p = 0.07$). There was no main effect of condition ($p = 0.47$), but there was a main effect of time ($p < 0.001$) and a main effect of sex ($p = 0.013$) with women experiencing less of decline in MVC at all time points. Immediately after exercise, force production was decreased by an average of -23.1% ($p < 0.001$) compared to Pre exercise values. After 60 seconds, force production remained down by -18% ($p < 0.001$). After 120 seconds, force output was remained decreased by

16% (p<0.001). After 180 seconds, force output was decreased by -11% (p=0.002). By 240 seconds, maximum force output was decreased by -7%, but it was not statistically different from beginning force (p=0.07). Finally, at 300 seconds force output was decreased -0.67% which was not statistically different than Pre (p=0.85).

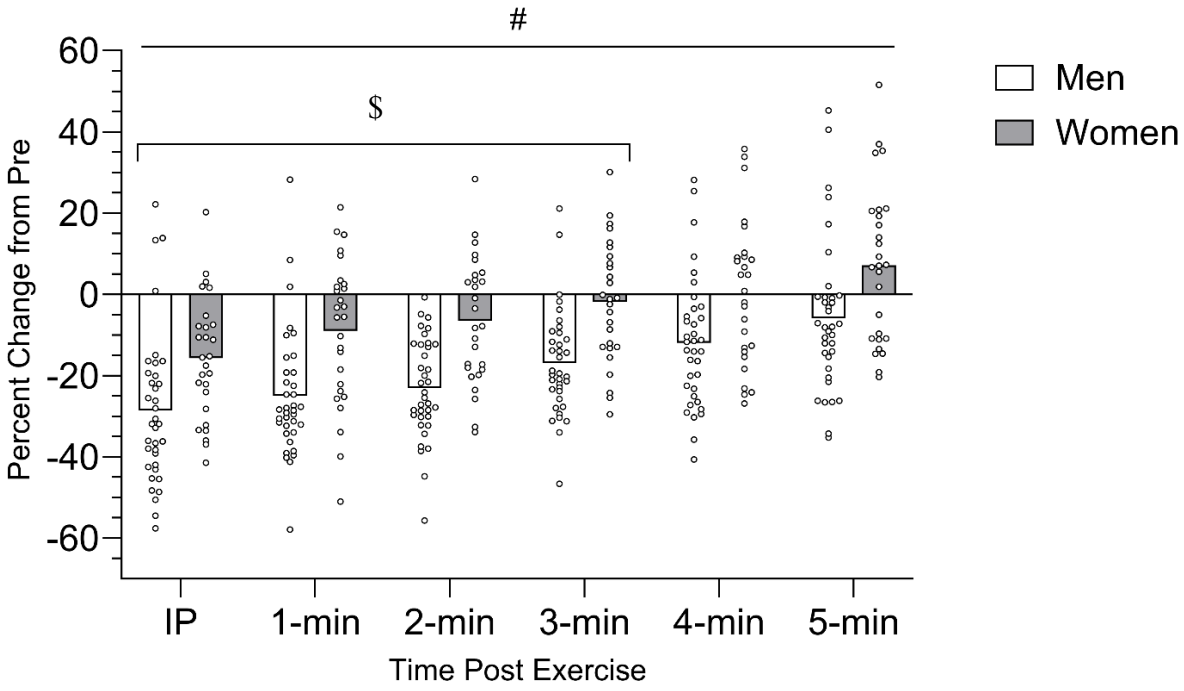

Figure 16 (above) – Percent change in MVC from pre-exercise values following fatiguing submaximal exercise. Data are collapsed across CON, IL, and CL conditions.
Values are means ± SD (n=22)
[#]Significant main effect of sex (p<0.05)
[$] Significant difference (main comparison) from "Pre" values (main comparison; p < 0.05)

Peripheral Fatigue following Fatiguing Submaximal Exercise

Peripheral fatigue following fatiguing exercise was measured by using percent change in twitch force in the post exercise MVCs. In a 3 x 7 x 2 ANOVA, there was no interaction between condition, time, and sex (p=0.49). There was also no interaction between condition and time (p=0.24) or condition by sex (p=0.43). There was not a main effect for condition (p=0.30) or sex (p=0.122). There was an interaction for time and sex

(p=0.045). Further analysis of the peripheral fatigue during fatiguing submaximal exercise was conducted with an independent samples t-test to determine at which time point the sex differences occurred. This showed that men and women had statistically significant differences in their peripheral fatigue levels immediately following exercise ($p<0.001$), 60 seconds after exercise ended (p=0.005) and 120 seconds after the end of fatiguing exercise (p=0.011). At 180 seconds after exercise, there was no sex difference (p=0.094) nor was there sex differences at 240 seconds (p=0.111) or 300 seconds (p=0.156).

When looking at peripheral fatigue in the women, there was a significant difference between twitch force prior to exercise and immediately following task failure ($p<0.001$), however it showed that there was no difference between twitch force before exercise and twitch force at 60 seconds (p=0.172), 120 seconds (p=0.578), 180 seconds (p=0.141), 240 seconds (p=0.282), and 300 seconds (p=0.086). This indicate that in women, twitch force and by extension peripheral fatigue was recovered 60 seconds after exercise failure.

When looking at peripheral fatigue and twitch force in men, there was a significant difference in twitch force prior to fatiguing exercise and immediately following exercise failure ($p<0.001$), 60 seconds following exercise failure ($p<0.001$), 120 seconds following exercise failure ($p<0.001$), 180 seconds following exercise failure ($p<0.001$), 240 seconds following exercise failure ($p<0.001$), and 300 seconds following exercise failure ($p<0.001$). This showed that men, regardless of pain condition, did not recover their twitch force and experienced higher levels of peripheral fatigue than women.

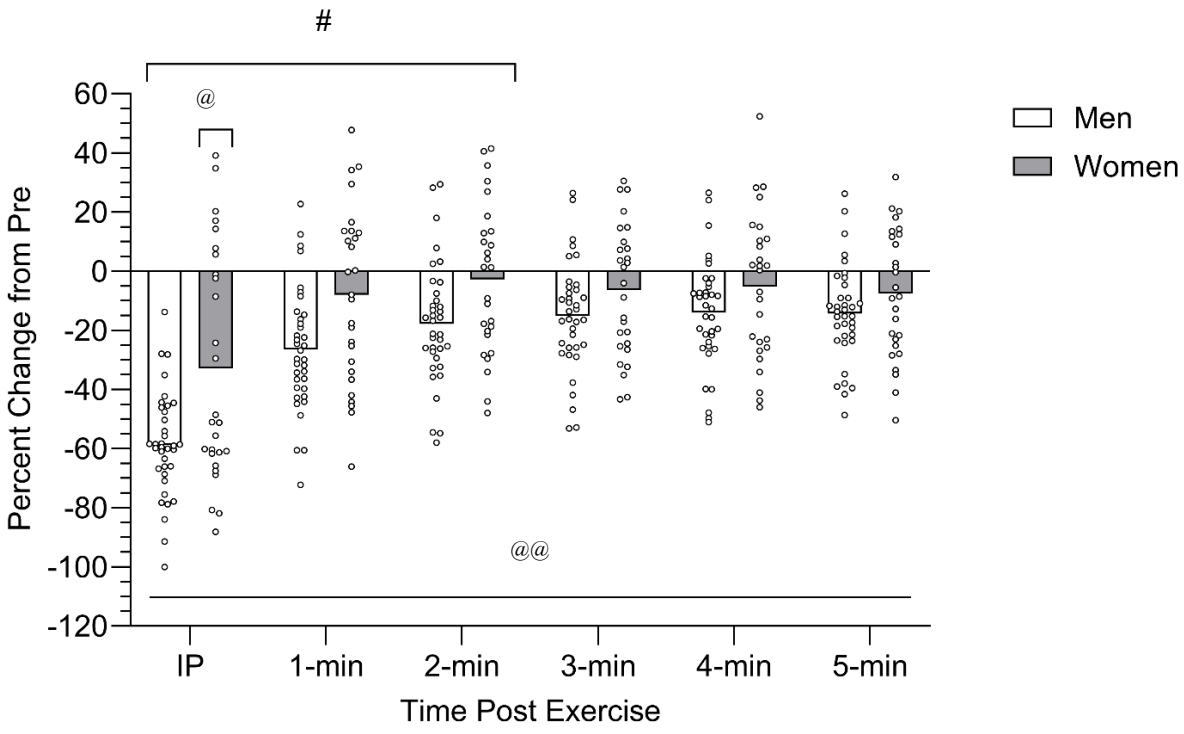

Figure 17 (above) – Percent change in twitch torque from pre-exercise values following submaximal fatiguing exercise. Data are collapsed across CON, IL, and CL conditions.
Values are means ± SD (n=21)
#Significant main effect of sex ($p<0.05$)
@ Denotes a significant difference in women vs Pre
@@Denotes a significant reduction from Pre at all time points for men
IP = immediately post failure

Central Fatigue following Fatiguing Submaximal Exercise

Central fatigue following submaximal exercise was measured using a 3 (condition) x 7 (time point) x 2 (sex) within subjects ANOVA. There was no 3-way interaction between condition, time, and sex ($p = 0.71$). There were no interactions between condition and sex ($p = 0.37$), time and sex ($p = 0.15$), or condition and time ($p = 0.72$). There was no main effect of condition ($p = 0.510$), time ($p = 0.19$), or sex ($p = 0.07$). This means that when comparing central fatigue before and after fatiguing submaximal exercise, there was no statistically significant change in central fatigue.

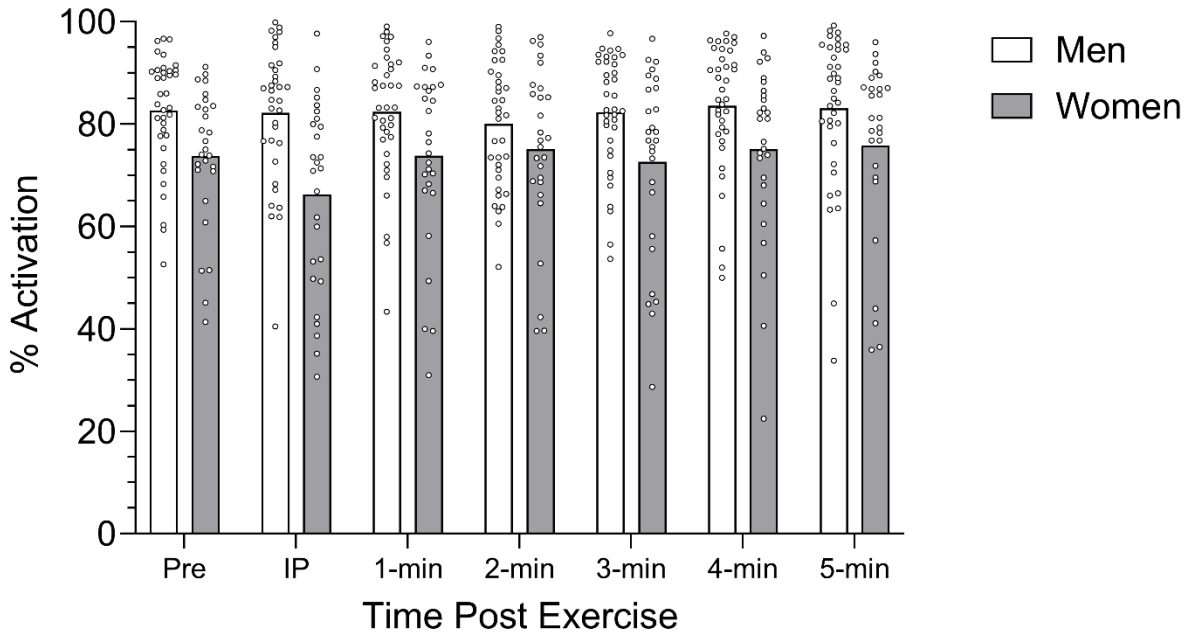

Figure 18 (above) –Percent activation change from Pre exercise and over 5 minutes of recovery following the TTF exercise protocol. Data are collapsed across CON, IL, and CL conditions.
Values are means ± SD (n=21)
Pre = baseline values, IP = immediately post failure

A 3 (condition) x 7 (time point) x 2 (sex) within subjects repeated measures ANOVA was used to determine muscle activation in the MVCs following fatiguing exercise. It was found that there was no 3-way interaction ($p=0.52$), no 2-way condition by time interaction ($p=0.72$), no 2-way time by sex interaction ($p=0.84$), no 2-way condition by sex interaction ($p=0.8$), no main effect of time ($p=0.11$), no main effect of condition ($p=0.65$) and no main effect of sex ($p=0.27$).

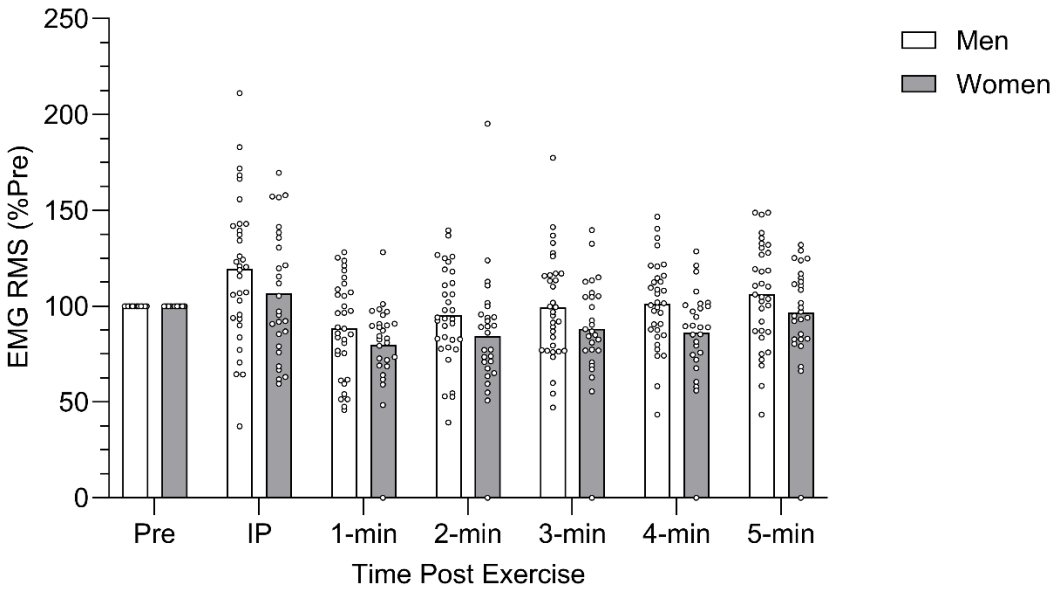

Figure 19 (above) – EMG RMS, expressed relative to pre MVC values during recovery from submaximal exercise.
Values are means ± SD (n=21)
Pre = Before fatiguing exercise; IP = Immediately Post, EMG = electromyography, RMS = root mean square, %Pre = percent change from baseline

Pain Ratings During Exercise

Exercising muscle pain

Data for pain ratings during exercise can be found in Table 5. A 3 (condition) x 5 (time point) x 2 (sex) within subjects repeated measures ANOVA was run to determine the change in subjective pain rating of the exercising muscle over time. There was no 3-way interaction ($p = 0.87$), no condition by time interaction ($p = 0.81$), no time by sex interaction ($p = 0.87$) and no condition by sex interaction ($p = 0.98$). There was no main effect of condition ($p = 0.97$) and no main effect of sex ($p = 0.68$). There was a main effect of time ($p=0.004$). A pairwise comparison was made to determine the change in pain rating over time where the pre-exercise pain rating (avg = 0.025) was compared to 30 seconds, 60 seconds, the last during exercise pain rating, and immediately following exercise failure. At 30 seconds, was an average pain rating of 0.510 and

there was no statistical difference in pain before exercise and after 30 seconds (p = 0.10). At 60 seconds, pain ratings increased to an average of 0.733 which was statistically different than the initial value (p = 0.030). The average of the last usable pain rating was 2.160 which was statistically different from the pain rating before fatiguing exercise (p = 0.004). Lastly, the average of perceived muscle pain immediately after failure was 1.936 which was significantly different than the initial pain rating (p = 0.007).

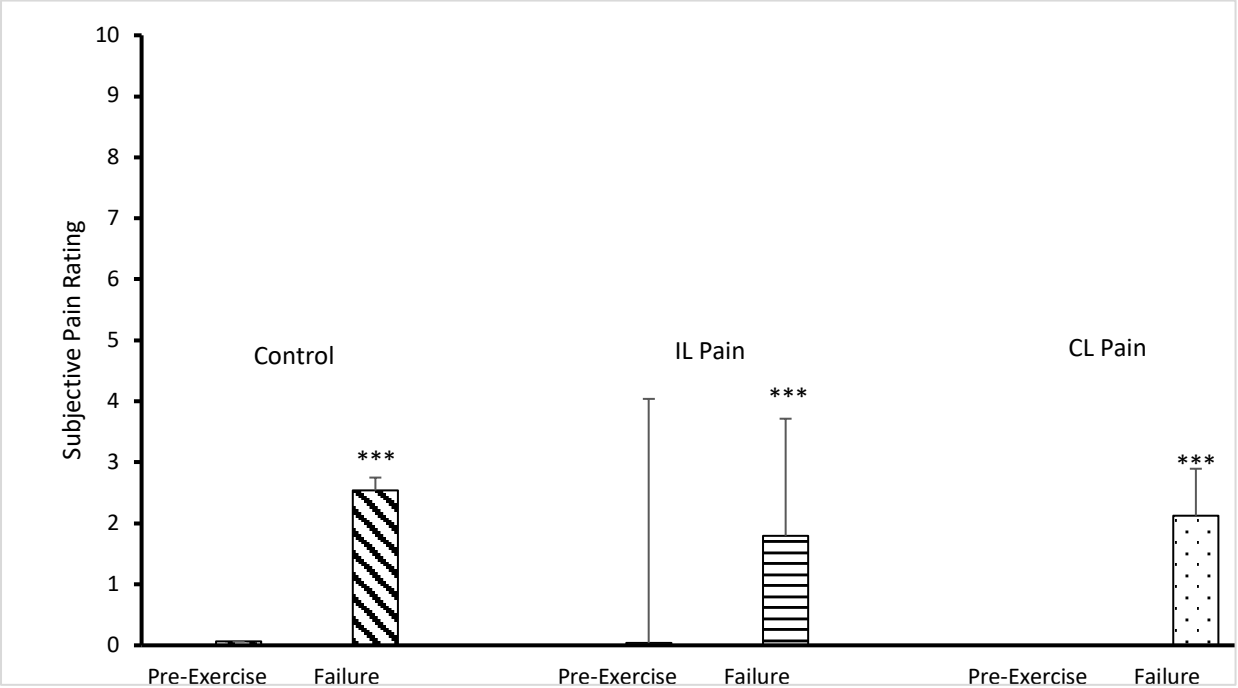

Figure 20 (above) - Subjective rating of exercising muscle pain before and immediately following failure during fatiguing exercise with electrically induced knee pain.
Values are means ± SD (n=22)
***Significant main effect of condition (location of pain; p<0.05)
IL = ipsilateral, CL = contralateral

Ipsilateral Knee Pain

A 3 (condition) x 5 (time point) x 2 (sex) within subjects repeated measures ANOVA was used to view the change in subjective pain rating of the ipsilateral knee pain throughout fatiguing submaximal exercise with and without electrically induced knee pain. It was found that there was

no 3-way interaction ($p = 0.75$), no time by sex interaction ($p = 0.53$), no condition by sex interaction ($p = 0.69$), and no main effect of sex ($p = 0.738$). There was a condition by time 2-way interaction ($p < 0.001$).

A 1-way ANOVA for the control condition and CL condition over time was not significant ($p > 0.17$). A 1-way ANOVA over time in the ipsilateral knee was significant ($p < 0.001$). Pain rating in the IL knee during the fatiguing exercise when stimulation was applied to the ipsilateral knee decreased significantly from the pre-exercise rating, at 30-second pain rating, 60-second pain rating, the final pain rating during exercise, and immediately following exercise failure where $p < 0.001$ for all comparisons. One-way ANOVAs were performed at each time point among the 3 conditions. The ANOVA was significant at each time point ($p < 0.001$). Within each time point, pain ratings were higher in the IL condition compared to the CL or CON conditions ($p \leq 0.008$ for each).

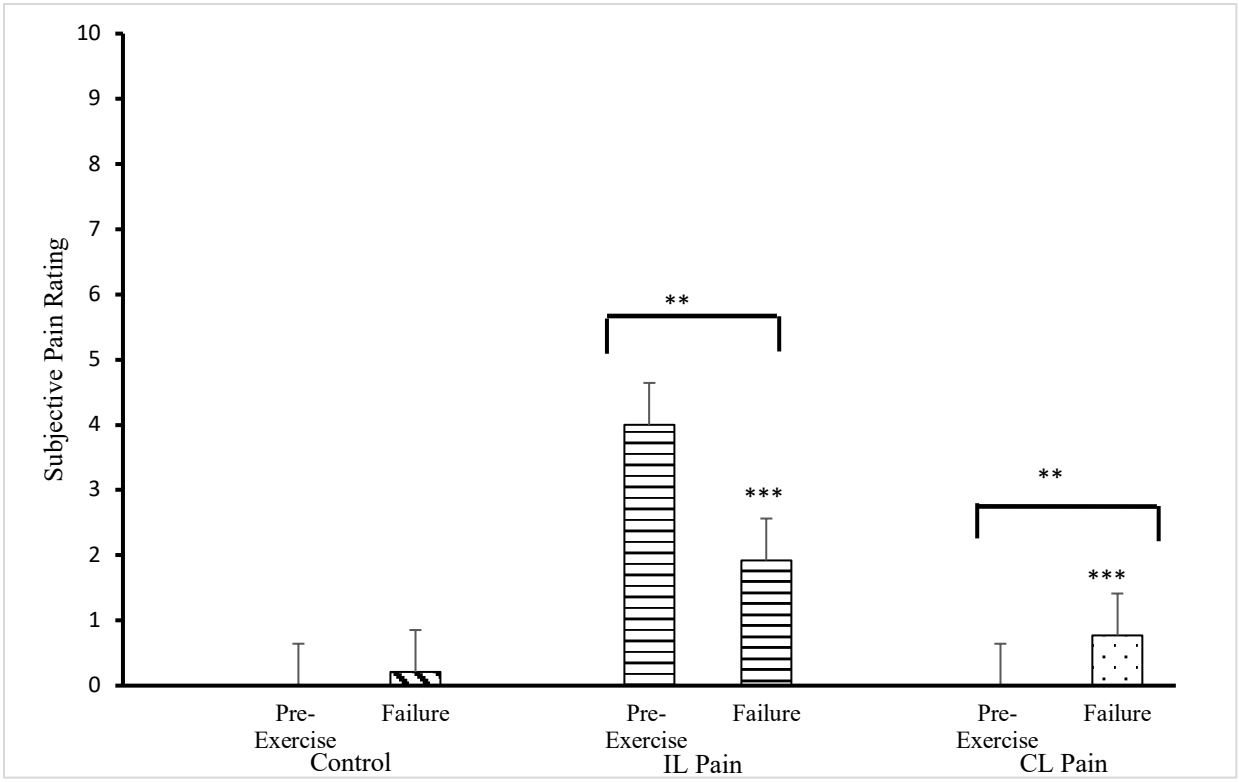

Figure 21 (above) – Subjective rating of the ipsilateral knee pain before and immediately following failure during fatiguing exercise with electrically induced knee pain.
Values are means ± SD (n=22)
**Significant main effect of time ($p<0.05$)
***Significant main effect of condition (location of pain; $p<0.05$)
IL = ipsilateral, CL = contralateral

Contralateral Knee Pain

A 3 (condition) x 5 (time point) x 2 (sex) within subjects repeated measures ANOVA was used to view the change in subjective pain rating of the contralateral knee pain throughout fatiguing submaximal exercise with and without electrically induced knee pain. There was no 3-way interaction ($p = 0.42$), no time by sex interaction ($p = 0.47$), no condition by sex interaction ($p = 0.79$) and no main effect of sex ($p = 0.81$). A significant condition by time interaction was found ($p = 0.002$).

A 1-way ANOVA for the control condition and IL condition over time was not significant ($p > 0.25$). A 1-way ANOVA over time in the CL knee was significant ($p < 0.001$).

Pain rating in the CL knee during the fatiguing exercise when stimulation was applied to the contralateral knee decreased significantly from the pre-exercise rating, at 30-second pain rating, 60-second pain rating, the final pain rating during exercise, and immediately following exercise failure where $p < 0.001$ for all comparisons. One-way ANOVAs were performed at each time point among the 3 conditions. The ANOVA was significant at each time point ($p < 0.02$). Within each time point, pain ratings were higher in the IL condition compared to the CL or CON conditions ($p \leq 0.03$ for each)

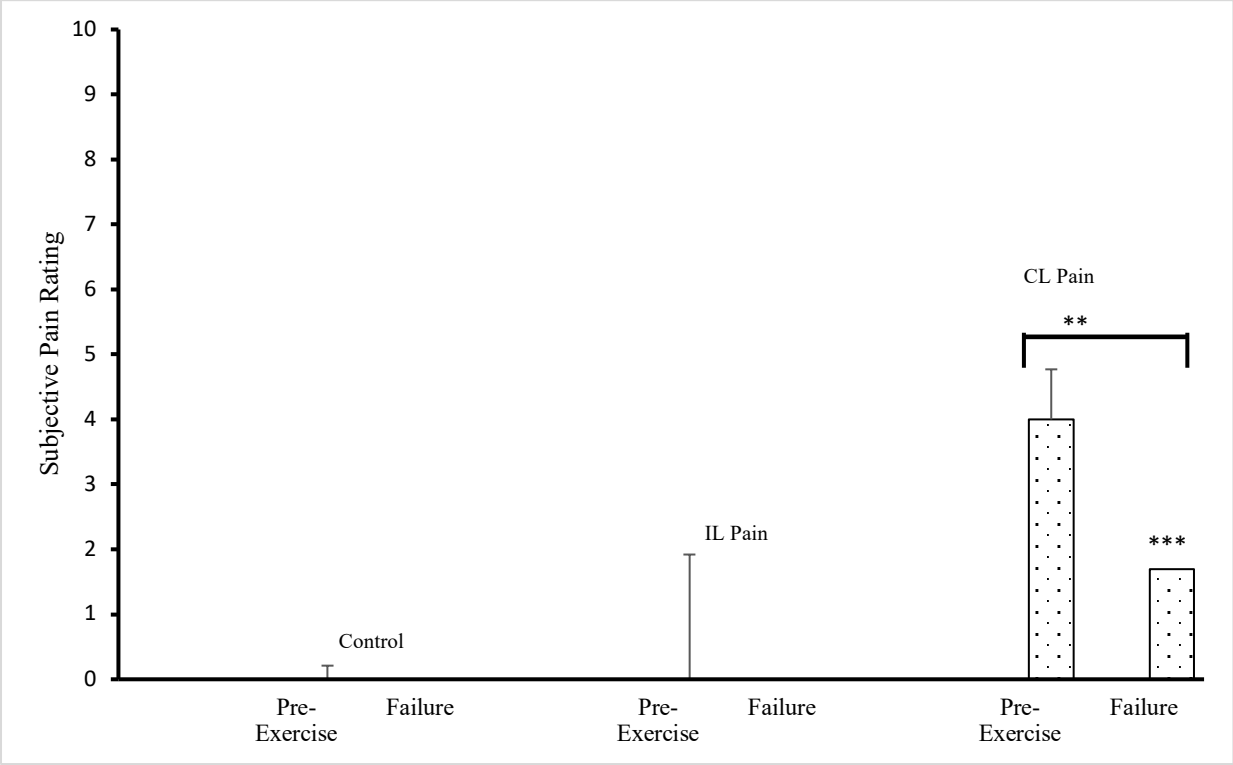

Figure 22 (above) - Subjective pain rating of contralateral knee before and immediately following failure during fatiguing exercise with electrically induced knee pain.
Values are means ± SD (n=22)
**Significant main effect of time ($p<0.05$)
***Significant main effect of condition (location of pain; $p<0.05$)
IL = ipsilateral, CL = contralateral

Table 6 – Muscle and Knee Pain Ratings Prior to and During Exercise

Variable	Sex	Control	IL	CL
IL Muscle Pain				
Pre-Exercise	M	0.13 ± 0.31	0.08 ± 0.29	0.00 ± 0.00
	F	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
30-Sec	M	0.75 ± 1.14	0.83 ± 1.03	0.83 ± 1.03
	F	0.50 ± 0.71	0.50 ± 0.73	0.67 ± 0.88
60-Sec	M	1.04 ± 1.03[$]	1.00 ± 1.18[$]	1.08 ± 1.31[$]
	F	1.00 ± 1.12[$]	0.33 ± 0.88[$]	0.67 ± 0.88[$]
Last Measured	M	2.42 ± 1.88[$]	2.25 ± 2.26[$]	2.17 ± 2.25[$]
	F	2.67 ± 2.74[$]	2.00 ± 1.79[$]	2.33 ± 3.24[$]
Failure	M	2.25 ± 2.09[$]	1.92 ± 2.39[$]	1.92 ± 2.27[$]
	F	2.83 ± 2.87[$]	1.67 ± 1.74[$]	2.33 ± 3.15[$]
IL Knee Pain[&]				
Pre-Exercise	M	0.00 ± 0.00	4.00 ± 0.00[b]	0.00 ± 0.00
	F	0.00 ± 0.00	4.00 ± 0.00[b]	0.00 ± 0.00
30-Sec	M	0.00 ± 0.00	1.17 ± 1.27[a,b]	0.00 ± 0.00
	F	0.00 ± 0.00	0.50 ± 0.71[a,b]	0.17 ± 0.33
60-Sec	M	0.00 ± 0.00	1.17 ± 1.27[a,b]	0.00 ± 0.00
	F	0.17 ± 0.33	1.00 ± 1.19[a,b]	0.33 ± 0.67
Last Measured	M	0.25 ± 0.87	1.33 ± 1.50[a,b]	0.04 ± 0.14
	F	0.00 ± 0.67	2.17 ± 2.64[a,b]	1.50 ± 2.98
Failure	M	0.25 ± 0.87	1.67 ± 1.61[a,b]	0.04 ± 0.14
	F	0.17 ± 0.71	2.17 ± 2.60[a,b]	1.50 ± 3.00
CL Knee Pain[&]				
Pre-Exercise	M	0.00 ± 0.00	0.00 ± 0.00	4.00 ± 0.00[b]
	F	0.00 ± 0.00	0.00 ± 0.00	4.00 ± 0.00[b]
30-Sec	M	0.00 ± 0.00	0.00 ± 0.00	0.96 ± 1.21[a,b]
	F	0.00 ± 0.00	0.00 ± 0.00	0.83 ± 0.83[a,b]
60-Sec	M	0.00 ± 0.00	0.00 ± 0.00	1.13 ± 1.21[a,b]
	F	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.97[a,b]
Last Measured	M	0.08 ± 0.39	0.00 ± 0.00	0.71 ± 1.42[a,b]
	F	0.00 ± 0.00	0.00 ± 0.00	2.50 ± 3.08[a,b]
Failure	M	0.00 ± 0.00	0.00 ± 0.00	0.88 ± 1.32[a,b]
	F	0.00 ± 0.00	0.00 ± 0.00	2.50 ± 3.08[a,b]

Values are means ± SD (n=22)

[$] Significant difference (main comparison) from "Pre" values (main comparison; $p < 0.05$)

[&]Significant condition x time interaction ($p < 0.05$)

[a] Significant difference from Pre (simple comparison; $p < 0.05$),

[b] Significant difference from the other conditions at that time point (simple comparison; $p < 0.05$)

IL = ipsilateral, CL = ipsilateral 30-sec and 60-sec = 30 and 60 seconds into exercise; Last Measured = final pain rating before task failure; Failure = pain rating immediately after task failure

Chapter 5: Discussion

The purpose of this study was to determine if maximal strength and time-to-task failure are impacted by the presence and location of experimentally induced knee pain. This was done by having participants complete a series of maximal contractions followed by a fatiguing exercise protocol designed to fatigue participants within 5 to 10 minutes, followed by post exercise assessments of force recovery. The primary findings of this study were: 1) experimentally applied knee pain decreased maximal strength regardless of whether the pain was applied to the ipsilateral or contralateral knee to the muscle being contracted, 2) time-to-task failure was not impacted by the presence or absence or location of knee pain, 3) knee pain did not impact measures of central or peripheral fatigue during the exercise bout, 4) knee pain during exercise did alter force recovery after exercise, and 5) experimental knee pain was reduced during exercise—termed hypoalgesia.

5.1 – Critical Torque and Maximal Strength

In an attempt to more accurately normalize exercise intensity for each person, the first measurements obtained were critical torque and maximal strength. Critical torque represents a critical threshold for fatigue development in the neuromuscular systems making it an ideal (but previously underutilized) measure for prescription of submaximal fatiguing exercise (Burnley et al., 2012). Burnley found in their 2012 study that contractions performed above CT resulted in participants reaching failure between 3 and 18 minutes whereas contractions performed 10% and 30% below critical torque resulted in participants sustaining exercise for 60 minutes. Similarly to Burnley, the present study found that when participants exercised at 15% over their CT they averaged a time-to-task failure of between roughly 6 and 8 minutes regardless of sex or

condition. In this context, our use of CT to prescribe a work rate during submaximal exercise was a clear success. An interesting finding of the present study was that participants who CT occurred at a lower percent of MVC, leading to exercise at a smaller percentage of their maximal strength, generally had a longer time-to-task failure. This finding was consistent with those of Abdalla et al., (2017) who found a higher absolute MVC negatively influenced exercise tolerance during submaximal isometric contractions. Further study of this relationship and the use of CT to prescribe exercise work rate could prove valuable.

Unsurprisingly, the present study found sex differences in MVC which was expected and consistent with findings from Harrison et al. (2023). The men were significantly stronger than the women, however there was no sex difference in absolute critical torque. When expressed relative to MVC, the males in this study had a critical torque that was 53% of their MVC while the females in the present study had a critical torque that was significantly higher at 66% of their MVC. Few studies have examined sex differences in CT, but data from our lab (Janzen, unpublished observations) as well as a recent dissertation from Chesbro et al (2023) have also found CT occurs at a higher percentage of their MVC compared to men.

5.2 – Knee Pain and Maximal Strength

This study found that MVC was decreased with the application of experimental knee pain, regardless of whether the pain was applied to the ipsilateral or contralateral knee. These results align with those found by Norbury (2021) where maximal strength was decreased following injection of hypertonic saline, resulting in pain rated at approximately 4-6, in the ipsilateral and contralateral vastus lateralis muscles. Ciubotariu et al., (2007) also found that MVC torque decreased significantly following hypertonic saline injection. Another study that looked at the impact of pain on maximal strength was one done by Endoh et al., in 2006. This

study injected hypertonic saline in the left biceps brachii and found that MVC was significantly decreased in the hypertonic saline condition versus the control condition. The present study based the electrically induced knee pain off of methodology used by Cabral et al, (2023) where they found that the knee pain reduced maximal force. Together, all of these results indicate that with the presence of pain, maximal strength may be decreased. We hypothesized that ipsilateral knee pain would decrease MVC more than contralateral knee pain, but this was not supported as MVC declined to a similar extent in both conditions.

Mechanistically, the decline in MVC appears to be related to central, rather than peripheral factors. Motor unit recruitment was assessed by the interpolated twitch during each MVC. The results of the present study found that percent activation consistently decreased during the application of knee pain. Although no one has examined the differences in percent activation and central fatigue in this way, the results of the study are in line with Norbury et al., (2022) where they found that there was a decrease in percent activation following application of pain during the fatiguing exercise at 1 minute, but not at 2 minutes. However, they did not strictly examine the central fatigue without the use of fatiguing exercise protocol. This is a limitation for the Norbury paper, because without separate visits for participants maximal strength to be tested, it is unclear if the presence of central fatigue or peripheral was due to painful stimulus or fatiguing exercise. Peripheral factors were examined using electrically stimulated twitches applied after each MVC. Our finding that, as expected, twitch torque was unaffected by the presence of knee pain taken together with the decline in motor unit recruitment (measures with interpolated twitch and EMG) provided clear evidence of sensory feedback from the knee pain reducing motor output.

5.3 – Time-to-task failure

Time-to-task failure was measured by having participants exercise at 15% above critical torque until they could no longer maintain the intended force output. Time-to-task failure was not altered by presence of knee pain regardless of location when applied. It was initially hypothesized that ipsilateral knee pain would decrease time-to-task failure more than contralateral knee pain or no knee pain. This was not supported by the findings of the present study. It was also hypothesized that contralateral knee pain would decrease time-to-task failure more than no knee pain was also not supported by the findings of the preset study. Our findings were in contrast to the findings of Norbury et al., (2022). In Norbury's study, it was found that time-to-task failure was decreased by 16% following painful hypertonic saline injection versus the control condition. Similarly, Smith et al. also found in a 2020 study that hypertonic saline injection decreased time to task failure significantly compared to the control and isotonic saline injections. The differences in the results of these studies compared to the present study could be due to the type of pain stimulus and/or exercise type and intensity. It is possible that the knee pain induced by the electrical stimulus had less of an effect than the injection of saline directly into the working muscle despite the hope that a similar initial pain intensity would result from each. It should be noted that while the initial application of the knee pain resulted in intensity ratings of 4 out of 10, the intensity fell, and then rose over time during the exercise bout. This is unlike what was seen the studies of Norbury et al. (2022) and Smith et al. (2020) where muscle pain following hypertonic saline injection rose over time.

5.4 – Fatiguing during Submaximal Exercise

MVC, twitch torque, and motor unit recruitment were analyzed every minute (MVC and %ACT) and every 30-seconds (twitch torque) throughout the duration of submaximal exercise. MVC did not decline during the first minute of exercise in any knee pain condition while the

final measured MVC and MVC taken immediately post task failure did show significant declines. The decline in maximal force does not appear to be due to the presence of knee pain per se, but rather due to the duration of exercise. This finding differs from the results that Norbury et al. (2022) who found that at 1 minute into exercise, maximal force had declined by 12% and at two minutes, force had declined by 11% (Norbury et al., 2022). It seems likely that the submaximal intermittent contractions used in the present study allowed for recovery between contractions, at least in the first minute of exercise.

The results of the present study showed that little to no central fatigue occurred during the time to task failure protocol regardless of the pain condition with the only difference being that in EMG results, the muscle activation was increased during the final submaximal contraction. Percent activation actually increased after the first minute of exercise, before declining back to pre-exercise levels. This finding is at odds with our finding that knee pain reduced motor unit recruitment during MVCs performed prior to the fatiguing bout of exercise. Norbury (2021) found that when hypertonic saline was injected into the contralateral vastus lateralis, percent activation decreased in the quadriceps from baseline to minute 3 of exercise but showed no further decrease. Additionally, in a separate study, Norbury (2022) also found that hypertonic saline injection in the ipsilateral leg decreased percent activation at minute 1 compared to the control condition, but not at any other time point during the fatiguing exercise. Smith et al., (2020) used sEMG in order to measure RMS and found that there was no main effect of condition, indicating that was no change in central fatigue over time regardless of injection of hypertonic or isotonic saline. These results indicate some level of central fatigue occurred, but that it was likely not the sole contributor to declines in performance.

Previous work has demonstrated that higher intensity exercise (closer to or at MVC) as well as the use of intermittent contractions does not lead to as much central fatigue as low intensity, constant contractions (like those used by Norbury). When taken in concert with the decline in knee pain experienced by our participants during the fatiguing exercise, this likely accounts for our lack of findings of central fatigue.

Twitch force increased 30 seconds into the fatiguing exercise. This was likely due to potentiation, but subsequently decreased significantly over time until task failure was reached—indicating peripheral fatigue occurred and did not differ among the knee pain conditions. A study by Thomas et al. (2016) found that after short duration and high intensity exercise peripheral fatigue was increased compared to lower intensity and longer duration exercise. With exercise being prescribed over the critical torque of the participants, it was expected that peripheral fatigue would be present. The results of this study regarding sex difference contrast those discussed by Albert et al., in 2006 where it was found that males had a greater rate of fatigue development than women in fatiguing leg contractions. It is possible that with exercise being prescribed over critical torque, any sex differences due to maximal and absolute strength are eliminated since all participants are working at the same relative intensity. If exercise were prescribed at a lower intensity, it is possible that the sex differences seen in other studies would appear.

5.7 – Force recovery following fatiguing exercise

In a 2007 study, Ciubotariu et al. conducted a study using the hypertonic saline injection to elicit pain in dorsal flexors and plantar flexors. They found that following fatiguing dorsiflexion exercise, force was fully recovered after 5 minutes and that there was no difference in force recovery between painful and control conditions. These results reinforced a 1995 study

published by Beelen et al. where voluntary force was fully recovered 3 minutes after fatiguing exercise on an isokinetic cycle ergometer. These results support what was found in the present study where force was fully recovered within 4 minutes after fatiguing exercise, regardless of pain location or presence. It was hypothesized that MVC force recovery will return to baseline levels slower following exercise with ipsilateral and contralateral knee pain compared to no pain, likely due to increased central fatigue during exercise from the painful stimulus. However, this was not supported by the results of the present study.

Central fatigue was measured in the post-exercise protocol to determine how long it would take for motor-unit recruitment to return to baseline levels and to see if central fatigue was present following failure after fatiguing exercise. It was hypothesized that motor unit recruitment would return to baseline levels slower following exercise with ipsilateral and contralateral knee pain compared to no pain, and this was not supported by the findings of this research. Central fatigue was not present regardless of pain presence or location following the fatiguing exercise protocol. The general lack of central fatigue during the TTF protocol and lack of change after exercise indicates that the fatigue mechanism(s) that led to task failure were likely peripheral. There was no change in EMG or RMS following fatiguing exercise protocol which is in line with the results from percent activation in the post-exercise MVCs.

From a peripheral fatigue perspective, it was hypothesized that twitch force would return to baseline levels slower following exercise with ipsilateral and contralateral knee pain compared to no pain and this hypothesis was not supported by the data. Interestingly, twitch torque demonstrated a sex difference during recovery that was not seen during exercise. This is likely because the post-fatiguing exercise protocol was based off of absolute strength and not relative strength. The women had a reduction of peripheral

fatigue and recovered their twitch force after 60 seconds, whereas men did not recover their twitch force to baseline levels over the 5-minute recovery period. This showed that men, regardless of pain condition, did not recover their twitch force and experienced higher levels of peripheral fatigue than women in the study. There was no impact of pain location on peripheral fatigue measures after exercise.

5.8 – Subjective pain ratings throughout fatiguing submaximal exercise

Pain intensity was measured in three locations throughout the duration of the fatiguing submaximal exercise. The pain rated on a 0-10 scale was recorded approximately every 30 seconds in the exercising muscle, ipsilateral knee, and contralateral knee.

It was found that in the exercising muscle, pain increased significantly through exercise which coincided with the findings of Norbury et al., in 2022 where muscle pain on the exercising leg increased throughout exercise. In the present study, exercising muscle pain was not impacted by the pain condition. This finding contradicts the findings from Norbury et al., (2022) where the subjects' peak muscle pain rating was significantly higher than it was in the pain condition. A strength of Norbury's study was that it recorded pain every 2s with the use of an electric analog scale where participants moved the rating continuously as they exercised. These findings did not support the hypothesis that muscle pain intensity during exercise would be rated higher during exercise with the application of ipsilateral knee pain compared to a contralateral knee pain stimulus or no knee pain. Additionally, the findings of the present study did not support the initial hypothesis that muscle pain intensity during exercise will be rated higher during contralateral knee stimulation compared to no knee pain stimulus.

When participants exercise in the ipsilateral knee pain condition, the pain in the ipsilateral knee was greater than in the contralateral knee and in the condition with no pain. The

ipsilateral knee pain also decreased over time, likely due to exercise induced hypoalgesia. These findings are supported by Cabral et al., (2023) where they found that a tonic pain stimulus given to participants prior to maximal exercise was decreased during the exercise indicating that when constant pain is applied to the knee prior to beginning of exercise, it seems to decrease in intensity without the electrical stimulus actually changings.

When participants exercise in the contralateral knee pain condition, the pain in the contralateral knee was significantly greater than the ipsilateral knee pain rating and in the control condition. Similarly to the ipsilateral pain, the contralateral knee pain rating decreased significantly over time which was also likely due to exercise induced hypoalgesia. These findings are supported by Norbury et al., (2021) where they discovered that with injection of hypertonic saline into the muscle belly of the contralateral limb, the pain rating was higher than it was in the control condition. However, with injection of the hypertonic saline in the contralateral muscle, pain increased through the duration of exercise whereas pain intensity decreased in the present study.

Limitations

There were a number of limitations/considerations that researchers faced through the completion of this project. The first was that exercise was prescribed at such a high intensity that the fatigue experienced was only peripheral. A second limitation that researchers faced was that the EMG electrodes picked up crosstalk from the electrical activity from the knee pain stimulus. Once this was noticed, the grounding electrode was moved to the knee not receiving painful stimulation. However, there was still additional electrical activity picked up and recorded. Another limitation researchers faced was regarding scheduling. All the participants had at least 48 hours to account for muscle soreness and muscle fatigue, however due to classes, work, and

life, some participants had to reschedule resulting in there being weeks, rather than days between visits.

Future recommendations

For continued research, it would be ideal to control food intake, sleep, and hydration status across the testing days. Pain perception can be altered by the hydration levels and controlling for that variable across the testing days would minimize potential variability. It would also be ideal to ensure that all participants meet the same exercise levels. In the present study, participants were included if they met or exceeded the ACSM's recommendations. This means that those who only did vigorous exercise were compared to people who do not necessarily get any other exercise aside from walking to classes on campus. Because of this, it could be possible that the results would be different if everyone met the exact same training status.

It is recommended that future research explore different exercise intensities and pain intensities. This could be done by increasing or decreasing either prescription to determine if there are different results.

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Institutional Review Board for the Protection of Human Subjects

Initial Submission – Board Approval

Date:	March 11, 2024	**IRB #: 16785**
To:	Christopher D Black, PhD	**Meeting Date**:

Approval Date: 03/10/2024
Expiration Date: 02/28/2025

Study Title: The Impact of Remote and Localized Knee Pain on Time-To-Task Failure and Fatigue Parameters in the Knee Extensor Muscles of Recreationally Active College Aged Individuals.
Study Status: Active - Open | CR Req

The University of Oklahoma Health Sciences Center's Institutional Review Board (IRB) reviewed the above-referenced research study at its regularly scheduled meeting and requested specific changes to the submission. On behalf of the IRB, I have verified that the specific changes requested by the convened IRB have been made and I grant final approval for this study.

Approval for this research is limited to the activities described in the approved protocol and application. In accordance with this approval, specific conditions for the conduct of this research are listed below, and informed consent from participants must be obtained as indicated.

Risk/Benefit Assessment: Greater than minimal risk - no prospect

Informed Consent Determination: Informed consent and research privacy authorization must be obtained using the currently approved, stamped forms. You must retain all original, signed forms.

Continuing Review Determination: As part of this approval, annual continuing review is required. You must promptly submit a Continuing Review/Final Closure Report Form and appropriate supporting documents to the IRB upon notification; approximately 60 days prior to the expiration date indicated above.

Principal Investigator Responsibilities:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations at 45 CFR 46 and/or 21 CFR 50 and 56.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB Policy.
- Maintain accurate and complete study records for evaluation by the HRPP quality improvement program and if applicable, inspection by regulatory agencies and/or the study sponsor.

- **The following are also required if applicable to this research study:**
- You may *not begin your study* until the contract through Office of Research Administration (ORA) is finalized and signed as per OUHSC Institutional policy.
- If this study involves external sites requiring a reliance agreement for OUHSC to serve as IRB of record, submit a modification to add each non-OU site and non-OU collaborator to the application after a reliance agreement has been finalized.

Study documents approved or accepted with this submission are listed below. If you have questions about this correspondence, contact the IRB at 405-271-2045 or irb@ouhsc.edu.

Sincerely,
Karen Beckman, MD, Chair

Institutional Review Board
Study documents associated with this submission:

Study Document			
Title	Version #	Version Date	Outcome
PAQ	Version 1.0	12/13/2023	Approved
PCS	Version 1.0	12/13/2023	Approved
POMS	Version 1.0	12/13/2023	Approved
PARQ+	Version 1.0	12/13/2023	Approved
Pain Intensity Scale	Version 1.0	12/13/2023	Approved
Menstrual History	Version 1.0	12/13/2023	Approved
IPAQ	Version 1.0	12/13/2023	Approved
Flyer	Version 1.2	12/20/2023	Approved
Email Script	Version 1.2	12/20/2023	Approved
Protocol	Version 1.2	12/19/2023	Approved
HIPAA Authorization 1	Version 1.1	12/19/2023	Approved
Study Consent Form			
Title	Version #	Version Date	Outcome

Main Consent Form	Version 1.6	12/19/2023	Approved

Information for Industry Sponsors: the columns titled Version Number and Version Date are specific to the electronic submission system (iRIS) and should not to be confused with information included in the Document and/or Consent title(s).

Consent Form to Participate in a Research Study
University of Oklahoma Health Sciences Center (OUHSC)
The University of Oklahoma Norman Campus

Study Title: The impact of remote and localized knee pain on time-to-task failure and fatigue parameters in the knee extensor muscles of recreationally active college aged individuals.

Sponsor: The Department of Health and Exercise Science

Principal Investigator: Christopher Black Ph.D.

Phone Number: (706) 255-3750

KEY INFORMATION ABOUT THE RESEARCH STUDY

You are being asked to participate in a research study. Research studies are voluntary and include only people who choose to take part. This consent form begins with a 'Key Information' section to provide important information to help you decide whether or not to participate in this study. More detailed information is provided after the key information. Please take your time, discuss this with family and friends, and ask the investigator and study team any questions you may have.

WHY HAVE I BEEN ASKED TO PARTICIPATE IN THIS STUDY?

You are being asked to participate in this research study because you are a recreationally active individual aged 18-35.

WHY IS THIS STUDY BEING DONE AND HOW LONG WILL IT LAST?

The purpose of this study is to determine if knee joint pain similar to osteoarthritis impacts exercise performance measures such as maximum strength and endurance. Also, researchers want to determine if the location of pain has an impact on the same exercise performance measures.

This study will last approximately 2 weeks. It will include five separate visits separated by 48 hours each. There will be no follow up.

WHAT WILL I BE ASKED TO DO IN THIS STUDY?

If you decide to participate in this study, you will be asked to complete five total visits where you will exercise with and without electrical stimulation applied to your knee to evoke moderate pain (4 out of 10 on a rating scale).

WHY MIGHT I WANT TO PARTICIPATE IN THIS STUDY?

If you agree to take part in this study, there will not be direct medical benefit to you. We hope that the information learned from this study will provide a more comprehensive understanding of how pain impacts exercise performance.

WHY MIGHT I NOT WANT TO PARTICIPATE IN THIS STUDY?

You may decide that you do not want to participate because of the exposure to external pain stimulus that is uncomfortable. Additionally, you may decide that 5 visits over two weeks is too large of a time commitment.

The researchers do not know all of the side effects that could happen. For a complete description of known risks, refer to the Detailed Information section of the consent form.

WHAT OTHER OPTIONS ARE THERE?

You may choose not to participate in this study.

HOW WILL PARTICIPATING IN THE STUDY AFFECT ME FINANCIALLY?

There is no additional cost to you if you participate in this study.

You will be compensated for your time with a gift card of $30 following completion of all 5 visits.

There is a $10 compensation for each of the 3 experimental visits (3-5). If you choose to withdraw from the study, you will receive a pro-rated compensation for the number of experimental visits that you do complete.

DETAILED INFORMATION ABOUT THE RESEARCH STUDY

The following pages of the consent form will provide you with more information about this study. Please take your time in reviewing this information and ask the investigator and study team any questions you may have.

HOW MANY PEOPLE WILL TAKE PART IN THE STUDY?

About 50 people will take part in this study at the University of Oklahoma (Norman Campus). All of these individuals will participate at this location.

WHAT IS INVOLVED IN THE STUDY?

Visit 1 – Familiarization: Written and verbal explanations of the experiment will be given, and all

questions from you will be answered prior to the signing of consent forms. Once written consent

is obtained, you will complete a series of surveys and questionnaires to ensure that you meet the requirements to complete the study. The forms that will be completed include a physical activity readiness questionnaire (PAR-Q+), international physical activity questionnaire (IPAQ), pain attitude questionnaire (PAQ), pain catastrophizing scale (PCS), and profile of mood states (POMS). Females will also fill out a menstrual cycle history form. The PAR-Q+ is a questionnaire that asks you about your health history and is intended to determine if participation in exercise is safe. The IPAQ is a form that asks questions about physical activity and allows researchers to determine if you meet activity levels for participation in the study. This form also breaks down vigorous, moderate and light intensities of exercise. The PAQ is designed to determine how willing you are to admit that they are in pain. The PCS is used to determine if you are a catastrophizer in response to pain. Both the PCS and PAQ will be used as a secondary analysis to see if there is any correlation between responses to pain and threshold measurements. You will be familiarized with the process of rating your pain intensity using a 0-10 scale. Following the paperwork, your height, weight, and age will be recorded.

Visit one will also include familiarization of procedures for testing maximum voluntary contraction (MVC) of the knee extensors, interpolated twitch technique (ITT), time-to-task failure (TTF), and application of the electrical stimulus to the knee to induce knee pain. MVCs are 6 second contractions that are the maximum force you can give. ITT is a technique used to measure central and peripheral fatigue by giving an electrical stimulus to the muscle during MVC contraction and immediately after. TTF is the maximum amount of time that you are able to exercise without failure or fatigue.

During the first visit, researchers will also record the KinCom dynamometer placement so that prior to your arrival for future visits, the KinCom will be positioned correctly to save time. The KinCom is a machine that includes a chair where participants are strapped in as well as a lever that is strapped to the participants ankle. While the knee is at 90 degrees, participants will kick forcefully against the lever and the force output will be measured. This is an isometric exercise, meaning that there will be no flexion or extension of the knee. This visit will last approximately 30 minutes depending on the time it takes to complete paperwork.

Visit 2 – Familiarization: The second familiarization visit will be further familiarization of MVC, ITT, TTF, and the electrical stimulus to induce knee pain. A POMS survey will be given at the beginning of this visit. During this visit, you will complete a Critical Torque (CT) test to determine critical torque as well as prescribed intensity during submaximal fatiguing exercise. The critical torque test is 5 minutes long and consists of thirty maximal contractions that each last 6 seconds and are separated by four seconds of rest. The contractions will start out extremely strong and will decline through the duration of the test. At the end of the test, the force output of the contractions will level off. The force output at the end of the 5 minutes is averaged and considered the critical torque. This visit will last approximately 20 minutes.

Visits 3-5 – Experimental: Visits three, four, and five will be identical except for the location of application of the pain stimulus which will be randomized and counter-balanced so that you and all other participants experience three conditions:

1. Pain in the ipsilateral (exercising) knee,
2. Pain in the contralateral (non-exercising) knee, and 3. A no knee pain condition to serve as a control.

When you arrive on the three experimental days, you will be given the POMS questionnaire and will then be seated on the Kincom. All electrodes will be attached to you at that time. MVC and ITT will initially be assessed. Two measures will be taken with no pain applied to the knee (if randomly assigned to a pain condition) followed by 2 assessments taken with pain applied for 5 seconds prior to and during the assessment. This will allow for a determination of the effects of knee pain on maximal strength. Following 5 minutes of rest, the time-to-task failure test will occur. You will perform intermittent isometric (not moving) contractions (6 second contractions followed by 4 seconds of rest) at a force equal to 15% above your CT. This will continue until you can no longer reach the target force for 2 consecutive contractions. During the TTF test, electrically stimulated twitch force will be assessed after every 3rd contraction (every 30-sec), and a MVC with ITT will be performed after every 7th contraction (every minute). Ratings of muscle pain in both the knee and overall pain will be obtained every 30-seconds as well. Once

task failure has been reached, a MVC will be performed every minute for 5 minutes to assess the recovery of force production. With these visits being task failure, the three experimental visits will last as long as you are able to exercise. In total, it is expected these visits will last approximately 20 minutes.

WHAT ARE THE RISKS OF THE STUDY?

With exercise, there is risk of soreness and injury, dizziness or light-headedness. The present study uses isometric knee extension exercise meaning that you will be seated and kicking against a fixed bar so there is no risk of falling. With the exercise being high intensity, it is likely that you will experience soreness.

TO WHAT EXTENT WILL MY INFORMATION BE KEPT CONFIDENTIAL?

Efforts will be made to keep your personal information confidential. You will not be identifiable by name or description in any reports or publications about this study. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law.

There are organizations outside the OUHSC that may inspect and/or copy your research records for quality assurance and data analysis. These organizations may include the US Food & Drug Administration and other regulatory agencies. The OUHSC Human Research Participant Program office, the OUHSC Institutional Review Board, OUHSC Office of Compliance, and other University administrative offices may also inspect and/or copy your research records for these purposes.

<u>Storing and Sharing Your Information:</u>

Your sample may be used for future studies without your additional consent. We will remove direct identifiers from your information and assign a code. The key to this code will be kept separately and only the researcher for this study will have access to the code. If your information is shared with another investigator for research purposes, they will not have access to the key code and will not be able to re-identify you.

CAN I WITHDRAW FROM THE STUDY?

You can stop participating in this study at any time. However, if you decide to stop participating in the study, we encourage you to talk to the researcher and your regular doctor first. If you choose to stop participating, you will not be compensated for the visits that have already been completed.

There may be circumstances under which your participation may be terminated by the investigator without your consent. This will happen if any of your

preliminary health questionnaires indicate that you do not meet study requirements.

WHAT IF I AM INJURED OR BECOME ILL WHILE PARTICIPATING IN THIS STUDY?

In the case of injury or illness results from this study, emergency medical treatment is available. There will be a researcher with you at all times that will be able to contact emergency health professionals.

You or your insurance may be charged for this treatment.

Complications arising as a result of the natural progression of an underlying or pre existing condition will be billed to you or your insurance. Please check with the investigator or with your insurance company if you have questions.

No other funds have been set aside by the University of Oklahoma Health Sciences Center to compensate you in the event of injury, illness, or for other damages related to your event of injury or illness.

WHAT ARE MY RIGHTS AS A PARTICIPANT?

Taking part in this study is voluntary. You may choose not to participate. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled.

If you agree to participate and then decide against it, you can withdraw for any reason and leave the study at any time. However, at certain times during the treatment, it may be harmful for you to withdraw, so please be sure to discuss leaving the study with the principal investigator or your regular doctor. You may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled.

You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study has completely finished. You consent to this temporary restriction.

You can receive more information regarding these rights in the Privacy Notice for Research Participants, located on the OUHSC Office of Human Research Participant Protection (HRPP) website at https://compliance.ouhsc.edu/HRPP/Participant/Privacy-Notice.

If you have any questions and requests, please contact the HRPP Office at 405-271-2045.

WHOM DO I CALL IF I HAVE QUESTIONS, SUGGESTIONS, OR CONCERNS?

If you have questions, concerns, or complaints about the study or have a research-related injury, contact Christopher Black Ph.D. at (706) 255-3750 or Caitlin Hubbard at (405) 802-8609.

If you cannot reach the Investigator or wish to speak to someone other than the investigator and for questions about your rights as a research participant, contact the OUHSC Director, Office of Human Research Participant Protection, at 405-271-2045.

SIGNATURE:

By signing this form, you are agreeing to participate in this research study under the conditions described. You have not given up any of your legal rights or released any individual or entity from liability for negligence. You have been given an opportunity to ask questions. You will be given a copy of this consent document.

I agree to participate in this study:

_____ _____ _____

PARTICIPANT SIGNATURE (age ≥18) Printed Name Date

_____ _____ _____

SIGNATURE OF PERSON Printed Name Date OBTAINING CONSENT

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRES IPAQ: SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken in 12 countries (14 sites) across 6 continents during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages. IPAQ is suitable for use in regional, national and international monitoring and surveillance systems and for use in research projects and public health program planning and evaluation. International collaboration on IPAQ is on-going and an international prevalence study is under development.

Using IPAQ

Worldwide use of the IPAQ instruments for monitoring and research purposes is encouraged. It is strongly recommended, to ensure data quality and comparability and to facilitate the development of an international database on health-related physical activity, that

- no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments,
- if additional questions on physical activity are needed they should follow the IPAQ items,
- translations are undertaken using the prescribed back translation methods (see website)
- new translated versions of IPAQ be made available to others via the web site to avoid duplication of effort and different versions in the same language,
- a copy of IPAQ data from representative samples at national, state or regional level be provided to the IPAQ data storage center for future collaborative use (with permission) by those who contribute.

More Information

Two scientific publications presenting the methods and the pooled results from the IPAQ reliability and validity study are due out in 2002.

More detailed information on the IPAQ process, the research methods used in the development of the IPAQ instruments, the use of IPAQ, the published papers and abstracts and the on-going international collaboration is available on the IPAQ web-site.

www.ipaq.ki.se

IRB NUMBER: 16785

This is the final SHORT LAST 7 DAYS SELF-ADMINISTERED version of IPAQ from the 2000/01 Reliability and Validity Study. Completed May 2001.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

IPAQ: SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS

NOTE: EXAMPLES OF ACTIVITIES MAY BE REPLACED BY CULTURALLY RELEVANT EXAMPLES WITH THE SAME METS VALUES (SEE AINSWORTH *ET AL*., 2000).

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. This is part of a large study being conducted in many countries around the world. Your answers will help us to understand how active we are compared with people in other countries.

The questions are about the time you spent being physically active in the last 7 days. They include questions about activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Your answers are important.

Please answer each question even if you do not consider yourself to be an active person.

THANK YOU FOR PARTICIPATING.

In answering the following questions,

- **vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder that normal.

- **moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder that normal.

1a. During the last 7 days, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling,?

Think about *only* those physical activities that you did for at least 10 minutes at a time.

_____ days per week 1b. How much time in total did you usually spend on one of those days doing vigorous physical activities*?*

or

_____ hours _____ minutes none

Again, think *only* about those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

2a. **_____ days per week** 2b. How much time in total did you usually spend on one of those days doing **or** moderate physical activities*?*

_____ hours _____ minutes

none

3a. During the last 7 days, on how many days did you **walk** for at least 10 minutes at a time? This includes walking at work and at home, walking to travel from place to place, and any other walking that you did solely for recreation, sport, exercise or leisure.

_____ days per week 3b. How much time in total did you usually spend walking on one of those days*?*

or

_____ hours _____ minutes

none

The last question is about the time you spent sitting on weekdays while at work, at home, while doing course work and during leisure time. This

includes time spent sitting at a desk, visiting friends, reading traveling on a bus or sitting or lying down to watch television.

4. During the last 7 days, how much time in total did you usually spend *sitting* on a **week day?**

____ hours _____ minutes

This is the end of questionnaire, thank you for participating.

2023 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or **NO**.	**YES**	**NO**
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** _____	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

☑ **If you answered NO to all of the questions above, you are cleared for physical activity.**
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm

If the above condition(s) is/are present, answer questions 3a-3d If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes

If the above condition(s) is/are present, answer questions 5a-5e If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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6. **Do you have any Mental Health Problems or Learning Difficulties?** This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. **Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. **Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. **Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. **Do you have any other medical condition not listed above or do you have two or more medical conditions?**

If you have other medical conditions, answer questions 10a-10c If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: _____

_____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
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The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References

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3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
4. Thomas S, Reading J, and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian Journal of Sport Science 1992;17:4 338-345.

01-11-2022

POMS™ Brief Form

BY DOUGLAS M. McNAIR, Ph.D., MAURICE LORR, Ph.D., JW P. HEUCHERT, Ph.D., & LEO F. DROPPLEMAN, Ph.D.

Client ID:_____ **Age:**_____ **Gender:** Male Female (Circle one)

Birth Date: ___/___/___ (Month Day Year) **Today's Date:** ___/___/___ (Month Day Year)

To the Administrator:

Place a checkmark ✔ in one box to specify the time period of interest.

To the Respondent:

Below is a list of words that describe feelings that people have. Please read each word carefully. Then circle the number that best describes

- ☐ how you have been feeling during the PAST WEEK, INCLUDING TODAY.
- ☐ how you feel RIGHT NOW.
- ☐ other: _____

If no box is marked, please follow the instructions for the first box.

POMS™

		Not at all	A little	Moderately	Quite a bit	Extremely
1.	Tense	0	1	2	3	4
2.	Angry	0	1	2	3	4
3.	Worn out	0	1	2	3	4
4.	Lively	0	1	2	3	4
5.	Confused	0	1	2	3	4
6.	Shaky	0	1	2	3	4
7.	Sad	0	1	2	3	4
8.	Active	0	1	2	3	4
9.	Grouchy	0	1	2	3	4
10.	Energetic	0	1	2	3	4
11.	Unworthy	0	1	2	3	4
12.	Uneasy	0	1	2	3	4
13.	Fatigued	0	1	2	3	4
14.	Annoyed	0	1	2	3	4
15.	Discouraged	0	1	2	3	4
16.	Nervous	0	1	2	3	4
17.	Lonely	0	1	2	3	4
18.	Muddled	0	1	2	3	4
19.	Exhausted	0	1	2	3	4
20.	Anxious	0	1	2	3	4
21.	Gloomy	0	1	2	3	4
22.	Sluggish	0	1	2	3	4
23.	Weary	0	1	2	3	4
24.	Bewildered	0	1	2	3	4
25.	Furious	0	1	2	3	4
26.	Efficient	0	1	2	3	4
27.	Full of pep	0	1	2	3	4
28.	Bad-tempered	0	1	2	3	4
29.	Forgetful	0	1	2	3	4
30.	Vigorous	0	1	2	3	4

Please ensure you have answered every item.

Department of Health and Exercise Science
University of Oklahoma

MENSTRUAL HISTORY QUESTIONNAIRE

Participant ID:_____Date:_____

We are asking you to give us as complete a menstrual history as possible. All information is strictly confidential.

Are you pregnant (circle your response)

YES- Do not complete the rest of this form

NO- Continue to section A.

SECTION A: CURRENT MENSTRUAL STATUS

1. Approximately how many menstrual periods have you had during the past 12 months? (please circle what months you have had a period. This means from this time last year to the present month)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

2. What is the usual length of your menstrual cycle (first day of your period to the next onset of your period)?

_____days. Today is day _____ of your present menstrual cycle.

3. When was the date of the onset of your last period?
4. When do you expect your next period?
5. What is the average length (number of days) of your menstrual flow? _____ days
   How many of these days do you consider "heavy"?_____days

6. Do you take oral contraceptives or any other medication that includes estrogen and/or progesterone?
   If yes, how long have you been taking this medication?_____
   What is the brand name and dosage of this mediation?_____

   Has this medication affected your menstrual cycle (regularity, length and amount of flow)? If yes, indicate changes.

Pain Intensity Scale

0 No pain at all

½ Very faint pain (just noticeable)

1 Weak pain

2 Mild pain

3 Moderate pain

4 Somewhat strong pain

5 Strong pain

6 Very strong pain

7

8

9

10 Extremely intense pain
(almost unbearable)

 Unbearable pain

PCS

Client No.: _____ Age: _____ Sex: M(__) F(__) Date: _____

Everyone experiences painful situations at some point in their lives. Such experiences may include headaches, tooth pain, joint or muscle pain. People are often exposed to situations that may cause pain such as illness, injury, dental procedures or surgery.

We are interested in the types of thoughts and feelings that you have when you are in pain. Listed below are thirteen statements describing different thoughts and feelings that may be associated with pain. Using the following scale, please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.

0 – not at all **1** – to a slight degree **2** – to a moderate degree **3** – to a great degree **4** – all the time

When I'm in pain ...

1. ☐ I worry all the time about whether the pain will end.
2. ☐ I feel I can't go on.
3. ☐ It's terrible and I think it's never going to get any better.
4. ☐ It's awful and I feel that it overwhelms me.
5. ☐ I feel I can't stand it anymore.
6. ☐ I become afraid that the pain will get worse.
7. ☐ I keep thinking of other painful events.
8. ☐ I anxiously want the pain to go away.
9. ☐ I can't seem to keep it out of my mind.
10. ☐ I keep thinking about how much it hurts.
11. ☐ I keep thinking about how badly I want the pain to stop.
12. ☐ There's nothing I can do to reduce the intensity of the pain.
13. ☐ I wonder whether something serious may happen.

_____

...Total

Participant #:_____
Testing session:_____ Date:_____

Pain Attitudes Questionnaire–Revised

Instructions

Rate how much you agree or disagree with each statement below using a 1 – 5 scale; **where 1 is Strongly Disagree and 5 is Strongly Agree.**

1. I take a long time to decide whether a sensation is painful or not

1 2 3 4 5

2. When I am in pain I should keep it to myself

1 2 3 4 5

3. When a sensation is mild, I tend to not trust myself in deciding whether it is painful or not

1 2 3 4 5

4. I keep a stiff upper lip when I am in pain

1 2 3 4 5

5. I lack confidence in making judgments about whether a sensation is painful or not

1 2 3 4 5

6. I think I can tolerate more pain than other people

1 2 3 4 5

7. I need time to decide whether a sensation is painful or not

1 2 3 4 5

8. I would rather not make a decision about pain when it is difficult to decide whether a sensation is painful or not

1 2 3 4 5

9. I think I can control my pain better than other people

1 2 3 4 5

10. I avoid making a decision about pain when I am not sure whether a sensation is considered painful or not

1 2 3 4 5

11. I take great care to avoid labelling a sensation as painful unless I am very certain

1 2 3 4 5

12. When I get odd sensations, I don't necessarily think they are painful

1 2 3 4 5

13. I tend to be reluctant to label a sensation as painful unless I am very certain

1 2 3 4 5

14. I am seldom emotional when in pain

1 2 3 4 5

15. I do not see any good in complaining when I am in pain

1 2 3 4 5

16. I go on as if nothing has happened when I am in pain

1 2 3 4 5

17. I maintain my pride and keep a stiff upper lip when I am in pain

1 2 3 4 5

18. I have good control over my pain compared to others

1 2 3 4 5

19. I make light of pain; I refuse to get too serious about it when in pain

1 2 3 4 5

20. Relative to other people, I am not as emotional when in pain

1 2 3 4 5

21. I get on with life despite being in pain

1 2 3 4 5

22. I hide my pain from others

1 2 3 4 5

23. I think I can endure more pain than other people

1 2 3 4 5

24. I need to be absolutely certain a sensation is painful before I will label it as painful

1 2 3 4 5

AUTHORIZATION TO USE or SHARE
HEALTH INFORMATION[1] THAT IDENTIFIES YOU FOR RESEARCH

An Informed Consent Document for Research Participation may also be required. Form 2 must be used for research involving psychotherapy notes.

Title of Research Project: **The impact of remote and localized knee pain on time-to-task failure and fatigue parameters in the knee extensor muscles of recreationally active college aged individuals**

Leader of Research Team: **Christopher D. Black, PhD**

Address: **1401 Asp Avenue, #110 SFC, Norman, OK, 73019**

Phone Number**: 706-255-3750 (cell) 405-325-7668 (office)**

If you decide to sign this document, University of Oklahoma Health Sciences Center (OUHSC) researchers may use or share information that identifies you (protected health information) for their research. Protected health information will be called PHI in this document.

PHI To Be Used or Shared. Federal law requires that researchers get your permission (authorization) to use or share your PHI. If you give permission, the researchers may use or share with the people identified in this Authorization any PHI related to this research from your medical records and from any test results. Information used or shared may include all information relating to any tests, procedures, surveys, or interviews as outlined in the consent form; medical records and charts; name, address, telephone number, date of birth, race, government-issued identification numbers, and nothing else.

Purposes for Using or Sharing PHI. If you give permission, the researchers may use your PHI to determine if it is safe for your to participate in the exercise used in this study.

Other Use and Sharing of PHI. If you give permission, the researchers may also use your PHI to develop new procedures or commercial products. They may share your PHI with other researchers, the research sponsor and its agents, the OUHSC Institutional Review Board, auditors and inspectors who check the research, and government agencies such as the Food and Drug Administration (FDA) and the Department of Health and Human Services (HHS), and when required by law. The researchers may also share your PHI with your physician and/or a University of Oklahoma physician in the event of a serious health risk or adverse event that occurs during the study.

Confidentiality. Although the researchers may report their findings in scientific journals or meetings, they will not identify you in their reports. The researchers will try to keep your information confidential, but confidentiality is not guaranteed. The law does not require everyone receiving the information covered by this document to keep it confidential, so they could release it to others, and federal law may no longer protect it.

YOU UNDERSTAND THAT YOUR PROTECTED HEALTH INFORMATION MAY INCLUDE INFORMATION REGARDING A COMMUNICABLE OR NONCOMMUNICABLE DISEASE.

Voluntary Choice. The choice to give OUHSC researchers permission to use or share your PHI for their research is voluntary. It is completely up to you. No one can force you to give permission. However, you must give permission for OUHSC researchers to use or share your PHI if you want to participate in the research and, if you cancel your authorization, you can no longer participate in this study.

Refusing to give permission will not affect your ability to get routine treatment or health care unrelated to this study from OUHSC.

Canceling Permission. If you give the OUHSC researchers permission to use or share your PHI, you have a right to cancel your permission whenever you want. However, canceling your permission will not apply to information that the researchers have already used, relied on, or shared or to information necessary to maintain the reliability or integrity of this research.

End of Permission. Unless you cancel it, permission for OUHSC researchers to use or share your PHI for their research will never end.

Contacting OUHSC: You may find out if your PHI has been shared, get a copy of your PHI, or cancel your permission at any time by writing to:

Privacy Official
University of Oklahoma Health Sciences Center
PO Box 26901
Oklahoma City, OK 73190

or Privacy Board
University of Oklahoma Health Sciences Center
PO Box 26901
Oklahoma City, OK 73190

If you have questions, call: (405) 271-2511 or (405) 271-2045.

Access to Information. You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study is completely finished. You consent to this temporary restriction.

Giving Permission. By signing this form, you give OUHSC and OUHSC's researchers led by the Research Team Leader permission to share your PHI for the research project listed at the top of this form.

Patient/Participant Name (Print): _____

_____ _____

_____

Signature of Patient-Participant or Parent if Participant is a minor | Date

Or

_____ _____

Signature of Legal Representative** | Date

**If signed by a Legal Representative of the Patient-Participant, provide a description of the relationship to the Patient-Participant and the authority to act as Legal Representative:

_____

OUHSC may ask you to produce evidence of your relationship.

A signed copy of this form must be given to the Patient-Participant or the Legal Representative at the time this signed form is provided to the researcher or his representative.

[1] **Protected Health Information includes all identifiable information relating to any aspect of an individual's health whether past, present or future, created or maintained by a Covered Entity.**

Email Recruitment

To whom it may concern,
Hello, my name is Caitlin Hubbard and I am a graduate student in the Department of Health and Exercise Science. Dr. Chris Black and I are looking for research participants for a study titled: The impact of remote and localized knee pain on time-to-task failure and fatigue parameters in the knee extensor muscles of recreationally active college aged individuals. We are conducting research looking at the impact of electrical pain stimulus on exercise performance, as well as if the location of pain impacts performance measures. If you are recreationally active and are between the ages of 18-35, a man, or a woman who is not pregnant and has had a regular menstrual cycle for the past six months, we invite you to participate! You must also be free of knee injuries for the previous 6 months and have not had any knee surgeries.

Participation in this research includes 5 visits that will last approximately 30 minutes each. Visit 1 will consist of consent paperwork, questionnaires, and familiarization of exercise protocol. Visit 2 will consist of one questionnaire and familiarization of protocol followed by a critical torque (CT) test which is a 5-minute test designed to assess your fatigue threshold. Visits 3-5 will be identical except for the location of the pain stimulus which will be randomized and counter-balanced so that you experience three conditions: 1. pain in the ipsilateral (exercising) leg, 2. the contralateral (non-exercising) leg, and 3. a no knee pain condition to serve as a control. Maximum voluntary contraction (MVC) and interpolated twitch (ITT) will initially be assessed. Two measures will be taken with no pain applied to the knee (if randomly assigned to a pain condition) followed by 2 assessments taken with pain applied for 5-seconds prior to and during the assessment. This will allow for a determination of the effects of knee pain on maximal strength. Following 5 minutes of rest, the time-to-task failure (TTF) test will occur. You will perform fatiguing exercise in the form of intermittent isometric (non-moving) contractions (6 second contractions followed by 4 seconds of rest) at a force equal to 15% above your CT. This will continue until you can no longer reach the target force for 2 consecutive contractions. During the TTF test, electrically stimulated twitch force will be assessed after every 3rd contraction (every 30-sec), and a MVC with ITT will be performed after every 6th contraction (every minute). Ratings of muscle pain in both the knee and overall pain will be obtained every 30-seconds as well. Once task failure has been reached, a MVC will be performed every minute for 5 minutes to assess the recovery of force production.

You will be compensated for your time. If you have any questions or would like to participate, please contact me at 405-802-8609 or caitlin.r.hubbard-1@ou.edu or contact Dr. Black at 705255-3750 or cblack@ou.edu.

All the best,
Caitlin Hubbard and Dr. Black
The University of Oklahoma is an equal opportunity institution IRB # 16785

IRB Number: 16785

Interested in the Impact of Pain on Exercise Performance?

Research Participants Needed

The Sensory and Muscle Function Lab is conducting a study titled:

The impact of remote and localized knee pain on time-to-task failure and fatigue parameters in the knee extensor muscles of recreationally active college aged individuals.

To participate

- Men and Women between 18-35 years of age.
- Healthy participants who are recreationally active (meets American College of Sports Medicine (ACSM) guidelines for physical activity) ○
- No recent history of knee injury or any previous knee surgeries

5 visits required

- Total time commitment is approximately 4 hours.
- Testing will take place in the Sensory and Neuromuscular Function lab at the University of Oklahoma Norman Campus. ○ You will be compensated for your time in the form of a gift card.

If you are eligible and interested please contact Caitlin Hubbard, caitlin.r.hubbard-1@ou.edu or Dr. Chris Black (Primary Investigator), cblack@ou.edu

The University of Oklahoma is an equal opportunity institution.

Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu	Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu	Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu	Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu	Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu	Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu	Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu	Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu	Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu	Caitlin Hubbard (405) 802-8609 Caitlin.r.hubbard-1@ou.edu

GENERAL INFORMATION

Participant ID: _____

Sex: M F

Height (cm): _____

Weight (kg): _____

KinCom Body Position

Chair (seat) _____

Leg _____

Moment Arm _____

VISIT 1

Visit 1

Date: _____ Time: _____

Consent Form Completed Yes No

HIPPA Completed Yes No

PAR-Q+ Completed Yes No

IPAQ Completed Yes No

PCS Completed Yes No

PAQ Completed Yes No

POMS Completed Yes No

Menstrual Cycle Regularity Form Completed Yes No N/A

Knee Pain

Threshold _____

Pain 4/10 _____

ITT Stimulation

Maximum Force Output _____

Stim Required _____

Familiarization of Protocol

Pre-Exercise Protocol

SWITCH TO PRE-EXERCISE PROTOCOL

Pain before starting pre-exercise MVC: Right Knee pain _____ Left knee pain _____

Exercising muscle pain _____

COUNTDOWN TO MVC

MVC 1 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			

1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 2 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 3 (with pain) _____

SWITCH PAIN ON

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 4 (with pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			

1 min into rest			
1:30s into rest			
1:55s into rest			

SWITCH TO FAMILIARIZATION FATIGUE PROTOCOL PPT

5 Minute TTF (60% of MVC for Visit 1)

MVC: _____

60% MVC: _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Before Starting			
3rd submax			
6th submax			
3rd submax			
6th submax			
3rd submax			
6th submax			

IMMEDIATELY BEGIN MVC AND START 60s TIMER

Post Exercise Protocol

MVC 1 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 2 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain

Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 3 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 4 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 5 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 6 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

Schedule visit 2

Date: _____ Time:_____

VISIT 2

Visit 2 Date: _____

POMS Completed Yes No

Knee Pain

Threshold _____

Pain 4/10 _____

ITT Stimulation

Maximum Force Output _____

Stim Required _____

BEGIN CRITICAL TORQUE TEST PPT

Critical Torque: _____

15% Above Critical Torque: _____

SWITCH TO PRE-EXERCISE PROTOCOL PPT

Pre-Exercise Protocol

Pain before starting pre-exercise MVC: Right Knee pain _____ Left knee pain _____

Exercising muscle pain _____

COUNTDOWN TO MVC

MVC 1 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 2 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 3 (with pain) _____

SWITCH PAIN ON

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 4 (with pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

SWITCH TO FAMILIARIZATION FATIGUE PROTOCOL PPT

5 Minute TTF (15% above CT for Visit 2)

CT: _____

Leg Weight: _____

15% above CT (-weight of leg): _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Before Starting			
3rd submax			
6th submax			
3rd submax			
6th submax			
3rd submax			
6th submax			

IMMEDIATELY BEGIN MVC AND START 60s TIMER

Post Exercise Protocol

MVC 1 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 2

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			

55s into rest			

COUNTDOWN TO MVC

MVC 3 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 4 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 5 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 6 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain

Immediately After MVC			
30s into rest			
55s into rest			

Schedule visit 3

Date: _____ Time:_____

Experimental Visit 3

Participant ID: _____

Date:_____

POMS Completed Yes No

Knee Pain

Threshold _____

Pain 4/10 _____

ITT Stimulation

Maximum Force Output _____

Stim Required _____

SWITCH TO PRE-EXERCISE PROTOCOL PPT

Pre-Exercise Protocol

Pain before starting pre-exercise MVC: Right Knee pain _____ Left knee pain _____

Exercising muscle pain _____

COUNTDOWN TO MVC

MVC 1 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			

1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 2 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 3 (with pain) _____

SWITCH PAIN ON

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 4 (with pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			

30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

SWITCH TO FATIGUE PROTOCOL PPT

Time-to-Task Failure

15% over CT (-leg weight): _____

Pain Condition (circle) Localized Pain Remote Pain No Pain

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Before Starting			
3rd submax			
6th submax			
3rd submax			
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3rd submax			
6th submax			
At Failure			

IMMEDIATELY BEGIN MVC AND START 60s TIMER

Post Exercise Protocol

MVC 1 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			

30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 2 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 3 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 4 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 5 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain

Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 6_____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

Schedule visit number 4

Date: _____ Time: _____

Experimental Visit 4

Participant ID: _____

Date:_____

POMS Completed Yes No

Knee Pain

Threshold _____

Pain 4/10 _____

ITT Stimulation

Maximum Force Output _____

Stim Required _____

SWITCH TO PRE-EXERCISE PROTOCOL PPT

Pre-Exercise Protocol

Pain before starting pre-exercise MVC: Right Knee pain _____ Left knee pain _____

Exercising muscle pain _____

COUNTDOWN TO MVC

MVC 1 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 2 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain

Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 3 (with pain) _____

SWITCH PAIN ON

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 4 (with pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

SWITCH TO FATIGUE PROTOCOL PPT

Time-to-Task Failure

15% above CT (-leg weight): _____

Pain Condition (circle) Localized Pain Remote Pain No Pain

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Before Starting			
3rd submax			
6th submax			
3rd submax			
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3rd submax			
6th submax			
At Failure			

IMMEDIATELY BEGIN MVC AND START 60s TIMER

Post Exercise Protocol

MVC 1 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 2 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain

Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 3 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 4 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 5 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 6 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

Schedule visit number 5

Date: _____ Time: _____

Experimental Visit 5

Participant ID: _____

Date:_____

POMS Completed Yes No

Knee Pain

Threshold _____

Pain 4/10 _____

ITT Stimulation

Maximum Force Output _____

Stim Required _____

SWITCH TO PRE-EXERCISE PROTOCOL PPT

Pre-Exercise Protocol

Pain before starting pre-exercise MVC: Right Knee pain _____ Left knee pain _____

Exercising muscle pain _____

COUNTDOWN TO MVC

MVC 1 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 2 (without pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain

Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 3 (with pain) _____

SWITCH PAIN ON

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

5 Second COUNTDOWN TO MVC

MVC 4 (with pain) _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
1 min into rest			
1:30s into rest			
1:55s into rest			

SWITCH TO FATIGUE PROTOCOL PPT

Time-to-Task Failure

15% above CT (-leg weight): _____

Pain Condition (circle) Localized Pain Remote Pain No Pain

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Before Starting			
3rd submax			
6th submax			
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6th submax			
At Failure			

IMMEDIATELY BEGIN MVC AND START 60s TIMER

Post Exercise Protocol

MVC 1 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 2 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain

Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 3 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 4 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 5 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

COUNTDOWN TO MVC

MVC 6 _____

Time (seconds)	Right Knee Pain	Left Knee Pain	Exercising Muscle Pain
Immediately After MVC			
30s into rest			
55s into rest			

EMG AND RMS

Participant ID and Visit Number	Pain condition	Contraction	RMS
		Pre-MVC (no pain)	
		Pre-MVC(no pain)	
		Pre-MVC (pain 4/10)	
		Pre-MVC (pain 4/10)	
		Submaximal 1	
		Submaximal2	
		Submaximal 3	
		Submaximal 4	
		Submaximal 5	
		Submaximal 6	
		MVC 1	
		Submaximal 1	
		Submaximal 2	
		Submaximal 3	
		Submaximal 4	
		Submaximal 5	
		Submaximal 6	
		MVC 2	
		Submaximal 1	
		Submaximal 2	
		Submaximal 3	
		Submaximal 4	
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		Submaximal 6	
		MVC 6	

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		Submaximal 4	
		Submaximal 5	
		Submaximal 6	
		MVC 9	
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		Submaximal 6	
		MVC 10	
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		Submaximal 4	
		Submaximal 5	
		Submaximal 6	
		MVC 11	
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		Submaximal 4	
		Submaximal 5	
		Submaximal 6	
		MVC 12	
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		Submaximal 3	
		Submaximal 4	
		Submaximal 5	
		Submaximal 6	
		MVC 13	
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		Submaximal 4	

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		Submaximal 6	
		MVC 15	
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		Submaximal 5	
		Submaximal 6	
		MVC 16	
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		Submaximal 6	
		MVC 17	
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		Submaximal 6	
		MVC 18	
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		Submaximal 6	
		MVC 19	
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		Submaximal 5	
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		Submaximal 6	
		MVC 21	
		Submaximal 1	

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		MVC 23	
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		Submaximal 6	
		MVC 24	
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		Submaximal 2	
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		Submaximal 4	
		Submaximal 5	
		Submaximal 6	
		MVC 25	
		Post MVC 1	
		Post MVC 2	
		Post MVC 3	
		Post MVC 4	
		Post MVC 5	
		Post MVC 6	